Color-Vision and Color-Blindness

Jennings

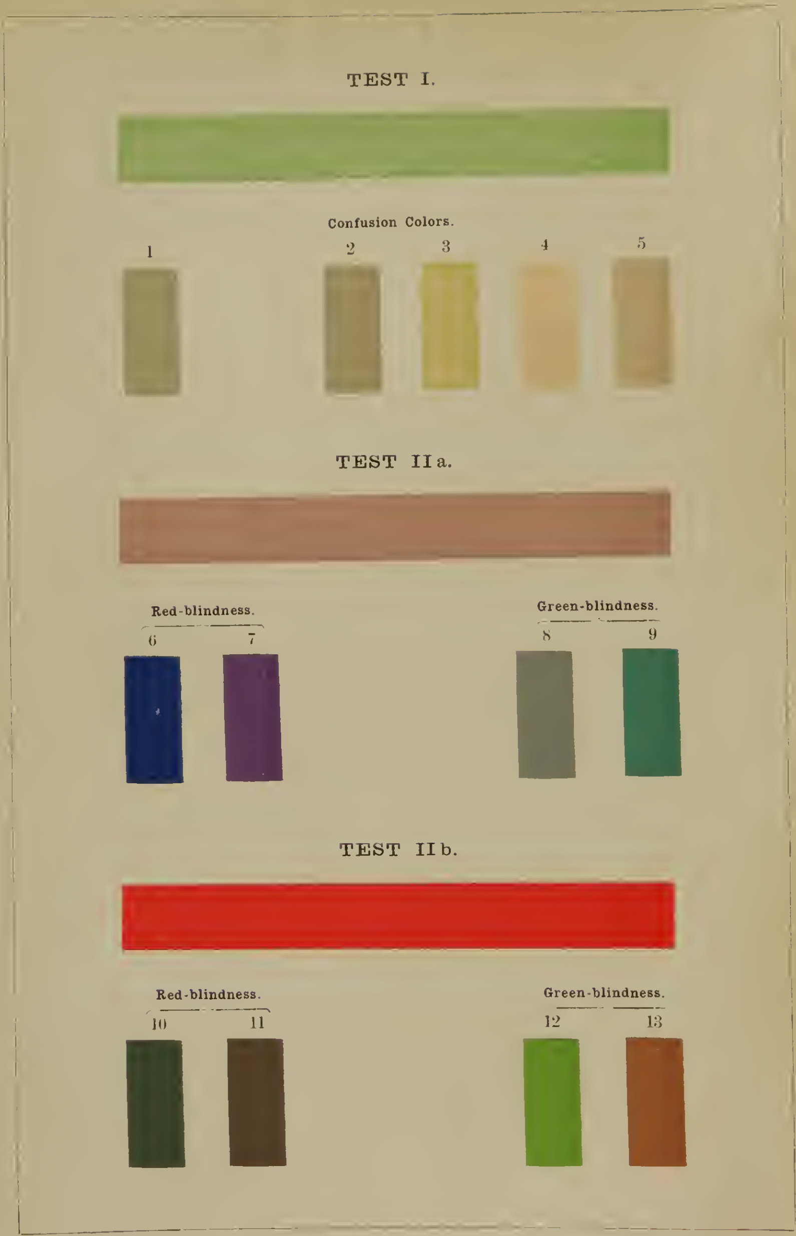

Plate Explanatory of Holmgren's Tests for Color-Blindness.
(After Holmgren.)

COLOR-VISION

AND

COLOR-BLINDNESS.

A Practical Manual for Railroad Surgeons.

BY

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WITH ILLUSTRATIONS.

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TO

CHARLES A. OLIVER, A.M., M.D.,

OF PHILADELPHIA.

THIS MANUAL IS DEDICATED,

AS A

SLIGHT TOKEN OF ADMIRATION FOR HIS MANY SCIENTIFIC CONTRIBUTIONS TO THE SUBJECT OF COLOR-VISION AND COLOR-BLINDNESS,

AND IN

GRATEFUL RECOGNITION OF MUCH PERSONAL KINDNESS,

BY

THE AUTHOR.

PREFACE.

For a long time the theoretical problem of color-blindness has engaged the attention of the scientific world. The practical side lay dormant for many years until it was proved that this curious defect was the cause of disastrous accidents by rail and sea. Public attention became aroused, new and simpler methods of investigation were invented, and, as a result of much agitation, many railroad and steam-ship companies now require their employés to submit to an examination as to their color-sense. Wilson in England, Helmholtz and Seebeck in Germany, Favre in France, Holmgren in Sweden, and Jeffries and Thomson in America have done much to stimulate this most necessary reform.

The methods now employed have proved practical and efficient, and there is every reason to believe that all the railroads in this country would take measures to weed out the color-blind from the service if the frequency and dangers of this affection were brought to their notice. It is with the hope of stimulating further effort in this direction that this manual has been written.

The author does not aim to be original, but has endeavored to produce a practical work on color-blindness which shall contain all that is essential to a perfect understanding of the subject, and to refer the reader to the proper authorities for many of the facts stated.

The author desires to tender his hearty thanks to Dr. James Thorington, of Philadelphia, for his many thoughtful and valuable suggestions.

2942 Washington Avenue, St. Louis.
January, 1896.

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Color-Vision and Color-Blindness.

CHAPTER I.

HISTORICAL SKETCH.

ALTHOUGH color-blindness must have existed for centuries, the first case noted in literature, according to Professor Wartmann, occurred in the practice of Dr. Tuberville in 1684. A woman, 32 years of age, came to consult him about her eyes. She had excellent vision in other respects, but could not distinguish one color from another.[1] In 1777 Mr. Huddart,[2] in a letter to Dr. Priestly, describes the case of a Cumberland shoemaker named Harris, who could distinguish in different colors only a greater or less intensity of light, calling all bright tints white and all dull ones black. Harris accidentally discovered his defect in childhood. Having picked up a child's stocking in the street he carried it to a neighboring house to inquire for the owner; he was struck with the fact that it was called a red stocking by the people, whereas to his eyes it appeared much the same as any other stocking. He also observed that his companions called cherries red and the leaves of the trees green, and, as he could only distinguish a difference by the size and shape, he was led to conclude that his vision must be defective. Harris had two brothers almost equally defective, one of whom always mistook orange for green.

"Mr. Harvey, of Plymouth, mentions a tailor who

could see in the rainbow but two tints, namely, yellow and bright blue. Black appeared to him sometimes green, sometimes crimson; light blue appeared as dark blue, crimson, or black; green was confounded with black and brown; carmine, red, lake, and crimson, with blue."[3]

Dalton,[4] the celebrated English chemist, was red-blind, and to him we owe the first accurate description of color-blindness. He did not suspect his defect for some time, but attributed his frequent mistakes to a faulty color nomenclature. In 1774 he published an account of his own case, and his interest in the subject led to the discovery of twenty persons possessed of the same peculiarity of vision as himself. He saw no difference between the color of a laurel-leaf and that of a stick of red sealing-wax; and the various tints of the rainbow were narrowed down to yellow and blue. On one occasion Dalton is said to have appeared at the Quaker meeting, of which he was a member, in the usual drab coat and small clothes of the sect, with a pair of flaming red-colored stockings. Many years later, when he was invested with the scarlet gown by the University, he compared its color to that of the trees. His defect caused him no annoyance, and he rather enjoyed the astonishment of his friends at his mistakes in colors.

From the fact that Dalton was the first observer to call attention to color-blindness the continental scientists gave it the name of *Daltonism*. Several English writers have objected to this name, saying that his memory should be perpetuated by reason of his valuable contributions to science, and not because of a congenital defect. Besides, as Dalton was red-blind, the name *Daltonism*

could only be correctly applied to that particular form of defect. Professor Whewell proposed the term *Idiopts*, signifying peculiarity of vision, but, as Sir David Brewster remarked, "the important consonant *p* would be very apt to be omitted in ordinary pronunciation, and so the last state of the *Idiopt* would be worse than the first." The term *color-blindness*, in general use at the present day, was first suggested by Brewster. Up to the year 1837 color-blindness was looked upon as a very rare affection; no practical method of investigation had been devised, and the cases seen were accidentally discovered. In this year Seebeck[5] examined the students of a school in Berlin, and began the systematic collection and comparison of cases. He rejected the idea of attempting to discover color-blind individuals by asking them to give the names of colored objects. The patient was directed to arrange, in the order of their resemblances to each other, about three hundred pieces of colored paper, which were in confusion. He also used pieces of colored glass and wool as test objects, but objected to silk on account of its brilliancy.

By comparing the manner of arranging the colors, Seebeck succeeded in pointing out two distinct classes of color-blindness. He also recognized the existence of many cases of partial defect, and of others where there was but a slight departure from the normal.

In 1850 Helmholtz, of Germany, brought to public attention the almost forgotten theory of the three primitive colors or fundamental perceptions devised by Thomas Young at the beginning of this century. Slightly modified, it seemed to offer a satisfactory explanation of color-blindness, and under the name of the Young-Helmholtz

Theory excited wide interest. Fifteen years later Hering announced the doctrine of four cardinal colors, which found much favor, and continues to rival the Young-Helmholtz Theory in the number of its adherents.

In 1854 George Wilson,[6] professor of technology at the University of Edinburgh, undertook the investigation of color-blindness from a practical stand-point. He was led to this study by the mistakes made by the students of his laboratory in judging the colors of chemical precipitates. For a long time he scarcely dared suspect any of his pupils of having so rare an infirmity; but, after reading Dalton's memoir, he proceeded to make an examination and found, much to his surprise, that his suspicions were correct. Wilson made a systematic search for color-blind individuals and established regular statistics on the subject. He examined soldiers, students, policemen, etc., and discovered 65 color-blind out of 1154 persons examined (5.6 per cent.), or 1 color-blind out of every 17.7 persons. In making his examinations he used pieces of colored paper or a colored diagram, and required the candidate to name the colors. Those who hesitated or failed in naming red, green, and brown were examined by Seebeck's test,—*i.e.*, classifying according to their analogy, but without indicating the name of the colors. Wilson's work was of great importance, as his constant aim was to direct attention to color-blindness in its connection with practical life. He shows that the color-blind are totally unfit to become painters, dyers, weavers, tailors, chemists, botanists, geologists, physicians, seamen, or railroad employés. He especially mentions the dangers which threaten travel by rail and sea because of the peculiar liability of the color-

blind to mistake the red (danger) and green (safety) signals in common use.[7]

About the same time that Wilson was calling public attention to this subject in England, Dr. Favre,[8] of Lyons, France, was engaged in investigating the color-sense among the employés of the Paris-Lyon-Mediterranean Company. His method consists in presenting to the candidate worsteds of different colors corresponding to those of the spectrum,—*red*, *orange*, *yellow*, *green*, *blue*, *indigo*, and *violet*,—and asking the name of each color. All who hesitate, fail, or make mistakes, even if they afterward correct them, are regarded as color-blind. In this manner he found 98 color-blind out of 1050 men examined (9.33 per cent.). His methods and results are not reliable, as he undoubtedly confounded color-blindness with the much more common condition of color-ignorance.

Notwithstanding the repeated warnings of Wilson as to the danger of employing color-blind men on railroads, little was done in a practical way until Professor Holmgren, of the University of Upsala, became interested in the subject.

In 1875 a serious railway accident occurred in Sweden, which intensely excited public attention. At the investigation which followed it was found that color-blindness was one of the principal causes of the disaster. From this fact Professor Holmgren became convinced that the color-sense of the employés should be under official control. To secure this reform he realized that it was of the highest importance to have a practical method of examination, which should be rapid and certain without incurring heavy expense or requiring

extensive preparations. After much study Professor Holmgren perfected his method, which is based on the Young-Helmholtz theory and has the merit of being at once simple, rapid, and accurate. The method was tested on 2220 soldiers, when it was found that one minute was the average time required to examine each man. Having secured a practical method, his next endeavor was to personally interest the railroad managers in the matter. As Holmgren says: "It naturally became an object of attention to railway officials, although received by a greater portion of them with a certain mistrust, seeing in it the result of a scientist's imagination or an overwrought solicitude, rather than a matter of practical application for the benefit of railways. 'If color-blindness really exist,' they said, 'it cannot, at any rate, be among the employés, or it would undoubtedly have been remarked; especially must this be the case among the engineers and conductors, as they rise from inferior grades and, consequently, have amply proved their ability to distinguish signals.'" Through the kindness of the superintendent-in-chief of the Upsala-Gefle line Holmgren was enabled to examine the entire *personnel* of the road, and discovered 13 color-blind men out of 266 individuals examined (4.8 per cent.). This inspection proved conclusively that color-blindness did exist among railroad employés without there having been the slightest suspicion of it. Through the efforts of Holmgren a law was enacted in Sweden under which no one can be taken into the employ of a railroad company until his color-vision has been tested and has been found sufficient for the duties he will be called upon to perform.[9]

CHAPTER II.

PHYSIOLOGICAL ANATOMY OF THE RETINA.

The eye has been likened to a photographic camera and the retina to the sensitive plate which receives the image of external objects. The impression thus made is carried along the optic nerve to the visual centres in the brain, where the conscious perception of the image occurs. In dealing with our subject we need only refer to the retina,—that delicate and sensitive expansion of the optic nerve which lines the interior of the eyeball. When examined under the microscope it is seen to consist of nerve-elements arranged in ten layers and a supporting matrix of delicate connective tissue. (See Fig. 1.) The *first layer*, or *membrana limitans interna* (*a*), is a delicate endothelial structure. which is separated from the vitreous body by the hyaloid membrane. The *second*, or *nerve-fibre layer* (*b*), consists of the axis-cylinders of the optic-nerve fibres, which turn at right angles and spread out into the *third*, or *layer of ganglionic cells* (*c*). These cells send forth tree-like branches, which go to make up the *fourth*, or *internal molecular layer* (*d*). The nerve-fibres now spread out into transparent, irregularly-shaped bodies, which form the *fifth*, or *internal nuclear layer* (*e*). The *sixth*, or *external molecular layer* (*f*), resembles the fourth layer in structure. The *seventh*, or *external nuclear layer* (*g*), is composed of fine nuclei of various shapes. The *external limiting membrane*, or *eighth layer* (*h*), is a mesh-work of connective-tissue fibres, which serves to bind together the

various layers just described. The nerve-elements passing through the connective-tissue layer terminate in the *ninth*, or *layer of rods and cones* (*i*). The rods are straight cylinders, which dip into the *tenth*, or *pigment-*

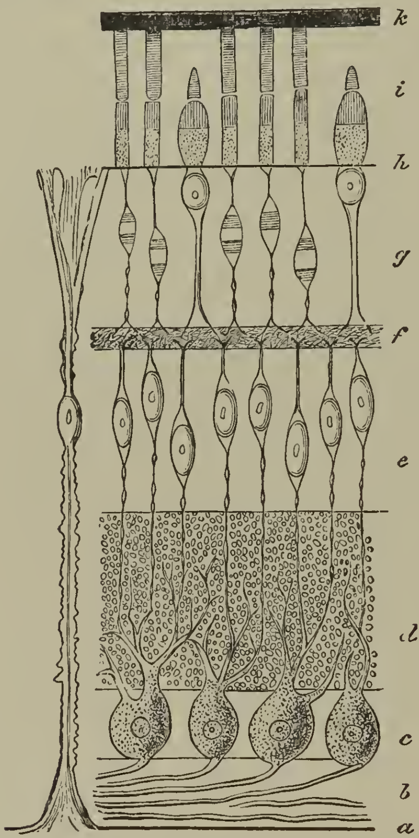


FIG. 1.—SECTIONAL VIEW OF RETINA. (*Schultze.*)

layer (*k*). According to Pacini,[10] the outer end of a rod bends on itself like a hook and connects with the end of a cone. The cones are conical or pear-shaped bodies one-half the length of the rods, and terminate in

a looped extremity. According to Norris and Wallace[11] (see Fig. 2), the looped extremity passes down over the body of the cone, and, after some convolutions in the position of the so-called external limiting membrane, winds along among the elements of the outer nuclear layer. The body of each cone is striated longitudinally and the neck of the cone transversely. This transverse

FIG. 2.—LAYER OF RODS AND CONES. $\times$ 900 Diam. (*Norris and Wallace.*)

marking was thought to indicate a structure composed of disc-like bodies, but Norris and Wallace find that the longitudinal markings can be traced from nearly the bases of the cones, and are seen to undergo a twisting which, on the necks of the cones, produces the transverse striations. As the looped extremities of the cones are buried in the retinal pigment, we are rarely able to see them, and it is only under the most favorable circum-

stances that the pigment is removed without destroying the delicate loops. The *tenth* or *pigment-layer* of the retina is closely attached to the choroid, and consists of a single layer of large, hexagonal cells, containing pigment-granules. Its cells have brush-like offsets, which enter between the outer segments of the rods (Alt).

There has been much discussion as to *what* elements in this complex structure originate the visual impulses. The phenomena of the blind spot and the figures of Purkinje seem to prove that the optic-nerve fibres themselves are insensible to light, and that the visual impulses originate in the region of the rods and cones.

Blind Spot of Mariotte.

Mariotte discovered that there is, in the visual field of each eye, a small area, corresponding to the entrance

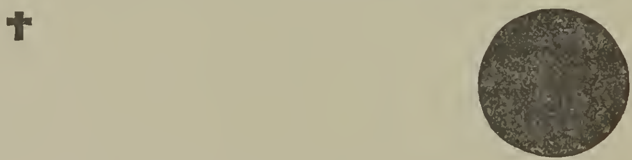


Fig. 3.—Diagram for Subjective Study of Blind Spot. (*Helmholtz.*)

of the optic nerve, which is insensible to light. This blind spot, or scotoma, can be demonstrated by closing the left eye and gazing at the cross in Fig. 3. As the book is moved slowly toward the eye, a point will be reached where the black spot becomes invisible. This phenomenon is not observed when both eyes are open, because of the overlapping of the two fields of vision. This experiment proves that the optic-nerve fibres, as they enter the eye, are insensible to light.

Purkinje's Figures.

If we stand in a dark room, and, while looking at the wall, move a candle to and fro at the side of and close to one eye, there will appear in the field of vision, projected on the wall, an image of the retinal vessels quite similar to that seen on looking into an eye with the ophthalmoscope. The field of vision is illuminated with a glare, and on this the branched retinal vessels appear as shadows. Since the blood-vessels reach to the external nuclear layer, this proves that the percipient elements of the retina must lie behind this point, either in the eighth layer or in the layer of rods and cones. As Müller traced the delicate radial fibres of the optic nerve through the various layers to an ultimate termination in the rods and cones, there is no doubt but that visual impulses originate in these end-organs.

The peculiar distribution of the rods and cones, together with our practical knowledge as to the sensibility of different portions of the retina, enable us to say that the cones are more sensitive than the rods. At the macula or central region, where vision is most acute, we find the several layers of the retina compressed. The rods are entirely absent and the cones are more abundant, thinned, and elongated. At the borders of this region a single circle of rods surrounds each cone, and as we pass toward the periphery of the retina the rods grow more and more numerous, while the number of cones diminishes in like manner. This arrangement is very suggestive when we remember that only objects in direct line of vision, those focused on the macula, are seen distinctly, and that all objects to the right or left of this central point are seen more or less indistinctly. We

conclude, therefore, that the cones are the most sensitive elements of the perceptive layer and are the essential factors in sharpness of sight.

Visual Purple.

The pigment-epithelium, which is so intimately connected with the delicate endings of the rods and cones, may be regarded as a glandular organ which secretes the visual purple. Boll[12] discovered that the visual purple was, in the living animal, susceptible to light. "He found that when the eye of a frog, which had been kept for some time in the dark, was rapidly opened, the outer limbs of the rods of the retina presented a very beautiful purple or rose color, which, after a few seconds, changed into a yellow and finally disappeared, leaving the rods colorless." If the frog had previously been exposed for some time to a bright light, the retina, even with the most rapid manipulation, was found to be colorless; and by examining at intervals the eyes of a series of frogs which, after being kept in the dark, had been exposed to light for variable periods, and, conversely, of frogs which, after an exposure to bright light, had been kept in the dark for variable periods, Boll was enabled to satisfy himself that, in the living eye, the color of the rods was destroyed by exposure to light and restored by rest in the dark. The visual purple is also bleached by monochromatic light, but the change is slower. Of the various prismatic rays the most active are the greenish-yellow rays, then the blues, and, least of all, the red rays.

The investigations of Kühne, Angelucci,[13] and Ayres[14] show that the grains of pigment, under the influence of

light, wander through the layer of rods and cones,—a phenomenon which is not observed in the dark. The pigment-cells, however, never retire completely from the rods, but constantly inclose the outer third. The time necessary for the ascent and descent of the pigment is exactly the same as that observed in the appearance and disappearance of the visual purple.

It is thought that the pigment-epithelium is intended for the protection of the rods, especially to neutralize the varying intensities of light upon the sensitive elements of the retina. As the visual purple is never found on the cones, and as the cones are the only elements found in the macula, distinct vision, both for objects and colors, is independent of its existence.

Field of Vision.

As we look about us the various objects that present themselves to view stimulate different parts of the retina at the same time. The impressions thus made are carried to the brain and there give rise to a co-ordinated perception, which corresponds to the physical image on the retina. The sum of these impressions, or, in other words, all that can be seen by an eye at the same moment, is called the *field of vision*. The various objects which go to make up this picture are not, however, seen with the same degree of distinctness.

We learn from anatomy that the cones, which are the most sensitive elements of the retina, are distributed unequally over its surface. Closely packed together at the macula, or central region, they steadily decrease in numbers as we approach the periphery. So with the retinal picture; distinct and well defined

at the fixation-point, it imperceptibly fades away into obscurity.

We measure the extent of the visual field by means of a perimeter. (See Fig. 4.) The patient sits in front

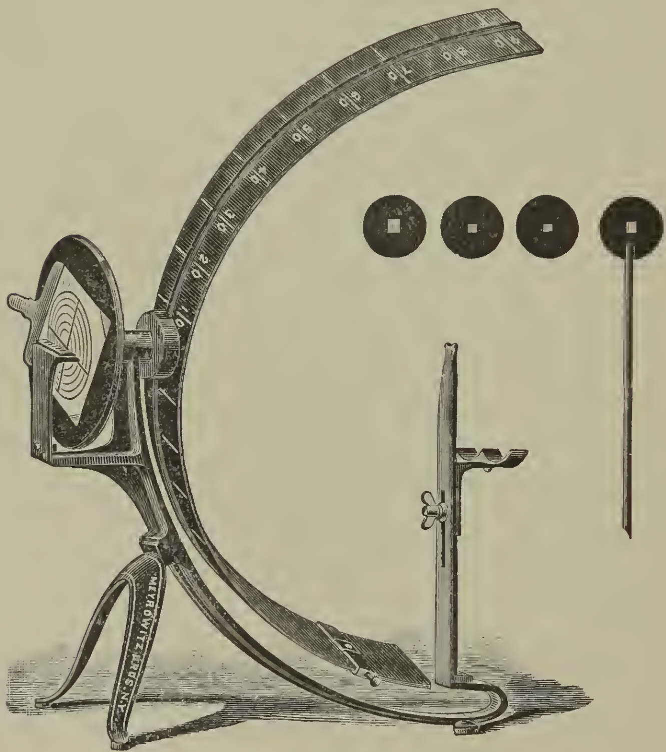


FIG. 4.—PERIMETER.

of the instrument with his back toward the light, and, having covered one eye, he rests his chin on the support and fixes the uncovered eye on the white dot in the centre of the semicircle. The test-object, a one-half-inch square of white or colored paper fastened in the sliding

carrier, is then slowly moved along the inner surface of the arc, from the periphery toward the centre, until it comes into view. This point having been noted on the chart, we turn the semicircle ten or twenty degrees and

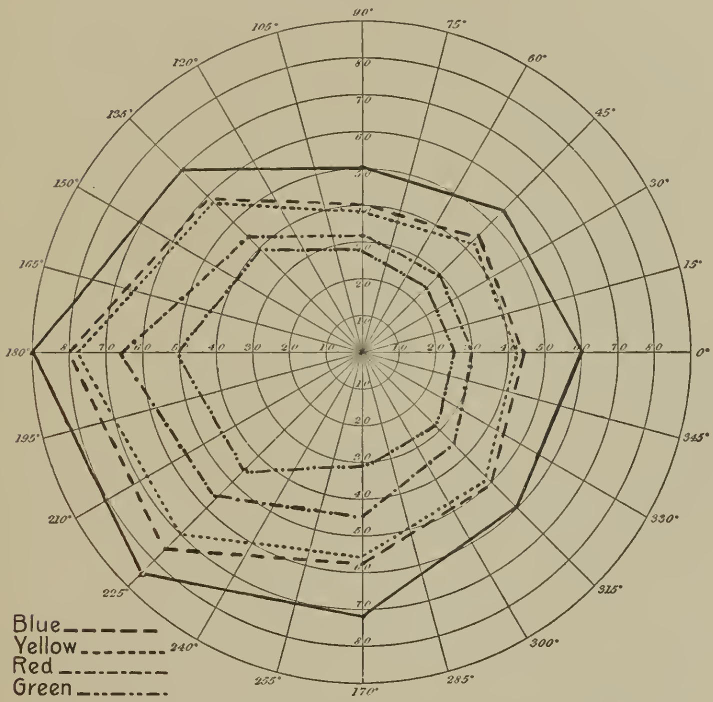


FIG. 5.—DIAGRAM OF THE NORMAL FIELD OF VISION FOR WHITE, BLUE, YELLOW, RED, AND GREEN.

The outer, continuous line indicates the limit of the field for white, and the broken lines indicate the limits of the color-fields.

proceed as before. In this manner the field of vision for white and colored objects may be mapped out and recorded for future use. The limits of the normal field for white and colors are shown in Fig. 5. In tabulated form it is as follows:—

	WHITE.	BLUE.	YEL-LOW.	RED.	GREEN.
Outward	90°	80°	Lies	65°	50°
Outward and up	70°	60°	close	45°	40°
Upward	50°	40°	by	33°	27°
Upward and in	55°	45°	blue.	30°	25°
Inward.	60°	45°		30°	25°
Inward and down	60°	50°		35°	27°
Downward.	72°	58°		45°	30°
Downward and out	85°	75°		55°	45°

A study of this table shows that the field of vision for white is most extensive outward and below and most restricted inward and above. This restriction is due partly to the presence of the edge of the orbit and nose and partly because the outer part of the retina is less used than the inner. Although the white square of paper is recognized within the above limits, it is not seen distinctly until it is close to the fixation-point. This region of distinct vision is quite limited, as can be shown by marking two black dots close together on a white square; at the fixation-point and over a small central area they are distinguishable from each other, but beyond this they appear as one. The phenomena observed when colored objects appear in the field of vision are peculiar. All colors beyond the blue line appear gray. Yellow and blue are the only colors which give rise to a normal color-sensation as soon as they become visible as colored. All other colors appear either yellow or blue until they pass inside of the blue-yellow area, when they are recognized in their natural colors. From this fact it would seem that we are totally color-blind in the peripheral

portion of the visual field, red-green blind in a middle zone, and have a perfect chromatic sense only over a small central area. There is, however, no absolute color-blindness in the peripheral portions of the retina, but merely a diminished color-sense; late researches show that, under sufficient illumination, each and every color is recognized up to the limits of the visual field. We conclude, from a study of the field for colors and the anatomy of the retina, that the cones are the elements of the perceptive layer which are most sensitive to colored light, and that the rods, while capable of responding to color-impressions under strong stimulation, usually only respond to differences in the quantity of the incident light. The Young-Helmholtz theory of color, which will be considered in Chapter IV, is based upon the supposition that the retina contains nerve-fibres some of which are sensitive to red, some to green, and some to violet light. This hypothesis, although not demonstrable in man, receives much support from the peculiar arrangement of the retinal elements in birds. These creatures, as we know, possess remarkable acuteness of vision, and it is but natural to suppose that the color-sense is as highly developed. The cones are much more liberally distributed over the retina in birds than in man, and at the apex of each cone is a colored globule of oil which only transmits light of its particular color. According to Carter,[15] Dr. Waelchli has examined the retinæ of many birds and finds "that, near the centre, green is the predominant color of the cones; while, among the green cones, red and orange ones are somewhat sparingly interspersed and are nearly always arranged alternately,—a red cone between two orange

ones, and *vice versâ.* In a surrounding portion, called by Dr. Waelchli the red zone, the red and orange cones are arranged in chains and are larger and more numerous than near the yellow spot. The green ones are of smaller size and fill up the interspaces. Near the periphery the cones are scattered, the three colors about equally numerous and of equal size, while a few colorless cones are also seen. It would be necessary to be thoroughly acquainted with their food in order to understand any advantage which the birds in question may derive from the predominance of green, red, and orange globules over others; but it is impossible to consider the structure thus described without coming to the conclusion that the birds in which it exists must have a very acute sense of the colors corresponding to the globules with which they are so abundantly provided, and that this color-sense, instead of being localized in the centre, as in the human eye, must be diffused over a very large portion of the retina."

CHAPTER III.

PHYSICS OF LIGHT. COLOR-SENSATIONS.

Solar Spectrum.

If a ray of solar light be made to pass through a prism, it is decomposed into a band of colored rays, which is known as the solar spectrum. Although the spectrum is made up of an infinite number of tints, we distinguish seven principal colors,—*i.e.*, red, orange, yellow, green, blue, indigo, and violet. The elongated

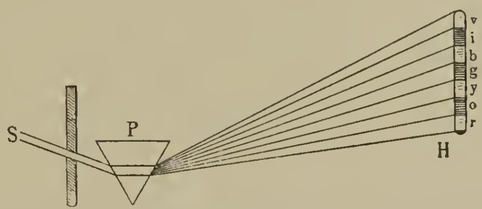


Fig. 6.—Diagram illustrating the Decomposition of White Light and Formation of the Solar Spectrum.

shape of the spectrum is due to the fact that the violet end is more *refrangible* than the red end, and in consequence the violet rays are deflected more to the base of the prism. (See Fig. 6.)

This quality of colored rays causes a slight degree of chromatic aberration which, in the eye, is hardly noticeable unless demonstrated by experiment. If we paste two narrow strips of paper, one red and the other violet, close to each other on a black ground, and look at them through a prism, we shall find that the red strip is displaced to a less extent than the violet; hence less

refrangible. Another experiment is to stand twenty feet from a candle or other small light and exclude all but the red and blue rays by looking through a cobalt-blue glass; the red and blue rays separate as soon as they reach the eye, and, as the blue rays are more refrangible,

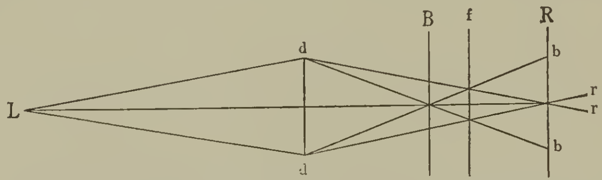


FIG. 7.—DIAGRAM ILLUSTRATING CHROMATIC ABERRATION.
d d, the dioptric surface; *d b*, the blue, and *d r*, the red rays; *B*, the focal plane of the blue, and *R*, of the red rays.

they come to a focus at *B* (Fig. 7), while the red rays focus at *R*. If the rays be supposed to fall on the retina at *B*, as they would in hypermetropia, we see a blue centre with a red fringe; if at *f* (emmetropia), the red and blue rays coincide, and we see a clear image of the

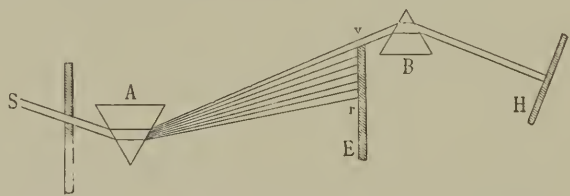


FIG. 8.—DIAGRAM ILLUSTRATING THE IMPOSSIBILITY OF FURTHER DECOMPOSING SPECTRAL RAYS.

cobalt; if at *R* (myopia), we see a red centre with a blue fringe.

The spectral rays are *saturated* or *simple* colors; that is, they cannot further be decomposed by a prism. If all of the rays of the spectrum, except the violet, be intercepted by means of the screen *E* (see Fig. 8), and if the violet rays be made to pass through a second prism,

refraction takes place, but the light received on the screen *H* remains unchanged.

RECOMPOSITION OF WHITE LIGHT.

White light which has been decomposed by a prism into the various colors of the spectrum may be repro-

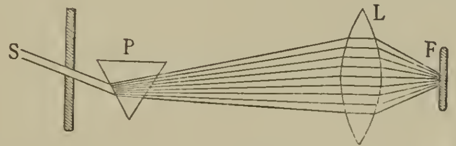


FIG. 9.—DIAGRAM ILLUSTRATING THE RECOMPOSITION OF WHITE LIGHT.

duced by combining the colored rays. If the spectrum be allowed to fall upon a double-convex lens (Fig. 9), the rays are re-united to form a pencil of white light on the screen *F*, placed at the focus of the lens.

That white light can be produced from a combina-

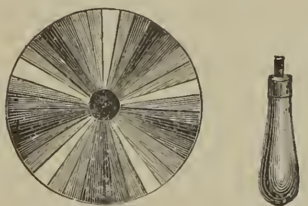


FIG. 10.—NEWTON'S DISC.

tion of the spectral colors can be demonstrated by means of Newton's disc. This consists of a card-board disc about one foot in diameter, upon which is pasted strips of colored paper to represent five spectra; the centre is covered with black paper. (See Fig. 10.) When the disc is rapidly rotated the retina receives the impression

of white (gray). It is not a pure white, because pigment-colors are not pure, and because it is difficult to arrange the colors in the same proportion as they exist in the spectrum.

This experiment may be explained by the fact that retinal impressions always last a little longer than the stimulus which gives rise to the impression. Hence, when the retina receives the impression of all the spectral colors in rapid succession, the impressions are mixed together and the resulting sensation is white (gray).

Mixed Colors.

Thus far we have only spoken of the simple, saturated colors of the spectrum; but in nature we find a large number of colors, tints, and hues which do not appear among the spectral colors. We find that colors such as purple, gray, and brown are mixtures of one or more spectral colors with white or black. Thus, a mixture of red and blue in certain proportions gives rise to the sensation of purple; a small amount of white mixed with black results in the sensation of gray, and brown is formed from a mixture of red, yellow, white, and black.

The qualities of a color depend upon tint, saturation, and intensity. *Tint* is that property of color which is due to a definite refrangibility or wave-length of the constituent rays. *Saturation* depends upon the more or less admixture of white light with the colors of the spectrum. The more white in the mixture, the less saturated will be the color. *Intensity* depends on the amplitude of vibration,—*i.e.*, the amount of colored light which falls on the same area of the retina in a given time.

Mixed colors may be produced by causing two or more colors of the spectrum to fall on the same part of the retina in rapid succession. The color-sensation resulting from this fusion is not the same as is made by a mixture of pigments of the same colors. Thus, a mixture of yellow and indigo of the spectrum gives rise to a sensation of white, while a mixture of yellow and indigo pigments appears green. This is a result of a partial absorption ; the indigo absorbs the red of the yellow and the yellow absorbs the blue of the indigo, so that only the green remains.

If pure pigment-colors are used we can obtain satisfactory results by mixing the sensations and not the pigments themselves. By means of Newton's disc the image of one color is brought to bear on the retina so soon after the image of another that the two sensations are fused into one.

Helmholtz secured the same result by causing the reflected image of one pigment to cover the direct image of the other. Place two pieces of colored paper a little distance apart on a table, one on each side of a glass plate inclined at an angle. By looking down with one eye on the glass plate the reflected image of the one paper may be made to coincide with the direct image of the other, the angle which the glass plate makes with the table being adjusted to the distance between the pieces of paper.[16]

Complementary Colors.

There are certain colors which, when mixed together in pairs, give rise to a sensation of white, and are said to be *complementary* to each other. These colors are :

red and *blue-green*, *orange* and *blue*, *yellow* and *indigo-blue*, *green-yellow* and *violet*, *purple* (non-prismatic) and *green*. A peculiarity of complementary colors is that they never can be perceived at the same time in the same color. If we look at a red object it is possible to see some blue or yellow mixed with it; but, however unreasonable the statement may seem, we can never say of a color that it is a mixture of red and green.

If we take red, green, and violet,—*i.e.*, the three colors most widely separated in the spectrum,—we can, by combining them in certain proportions, produce white. It follows, therefore, that all possible colors may be constructed from a mixture of red, green, and violet; hence these colors are called *fundamental* or *primary* colors.

After-images.

The sensation of light lasts much longer than the stimulus that produces it. The change set up in the retina by an electric flash has a duration much greater than that of the flash itself, and, as long as this change continues, we have the sensation of light, though the exciting cause has ceased to act. There must, therefore, at all times and from every object, be a tendency to the production of after-images; but they seldom cause annoyance, because they are lost in the overwhelming effect of direct impressions and effaced from the retina in the intervals of repose. We can readily demonstrate the presence of after-images in the following manner: If, on waking, the eye be directed to the window for an instant, and then closed, an image of the window, with its bright panes and darker sashes, will remain for a few seconds. This appearance, called a *positive* after-image, is instantly

succeeded, if we turn the eye toward the light, by a *negative* after-image, in which the bars appear light and the panes dark. This may be explained by fatigue of the eye. The part of the retina which has received the luminous image remains for a time in an excited state, while that which has received a dark image is in an unexcited state. The eye now being directed toward the light, the rays produce upon the excited parts of the retina a much more feeble impression than upon the parts which are as yet unexcited. As a result, we have a reversal of the light and dark parts of the image. The after-images which are produced by looking at a very intense light—for instance, the sun—may persist for a long time, causing much annoyance and sometimes serious injury to the eye. Boyle[17] relates the case of an eminent scholar, "who, from looking at the sun through a telescope, without any colored glass to take off the splendor of the object, brought on such an ocular spectrum that, nine or ten years afterward, he still saw, on turning toward a window or any white object, a globe of light of about the bigness with which the sun originally appeared to him." Sir David Brewster[18] "found, after his experiments, that his eyes were reduced to such a state of extreme debility that they were unfit for any farther trials. A spectrum of a darkish hue floated before his left eye for many hours, succeeded by the most excruciating pains, shooting through every part of the head. Two years after, the debility of the eyes still continued, and several parts of the retina in both eyes had completely lost their sensibility."

Colored objects also give rise to colored after-images. If we gaze fixedly for some time at a red spot on a white

ground, and then turn the eyes to a white surface, we shall perceive a spot of green of the size and form of the red spot. This *negative* image is always of a color complementary to that of the object. Thus, the negative image of blue is orange, of green is pink, and so on. Colored after-images can only be partially explained as the result of fatigue. The eye, when long fixed upon—say—a red object, is rendered insensible to the red rays, but is still sensitive to impressions of the other rays of the spectrum. If the eye be now turned to a white surface, being no longer sensible of red, the negative image is a compound of the remaining rays of white light, or greenish blue. This view, although explaining in a satisfactory manner some of the phenomena, is not sufficient for the whole. Negative images make their appearance when the eye itself is in perfect darkness. Thus, if we gaze for a little time at a bright light and then close our eyes, a luminous spot will appear which slowly changes through all the colors of the spectrum.

Joseph Henry[19] relates the case of a lady who was thrown into a paroxysm of terror by a negative after-image. "She had been for some hours attentively sewing on a bright-crimson dress, when her attention was directed toward her child, who, in its sport, had thrown itself on the carpet; its face appeared of the most ghastly hue, and the affrighted mother screamed in agony that her child was in convulsions; the other inmates of the house hastened to her assistance, but they were surprised to find the little one smiling, in perfect health. The sanity of the mother became the natural object of solicitude, until the effect was properly referred

to the impression made on her eyes by the crimson cloth."

Color of Objects.

The color of an object depends upon its power to absorb certain portions of white or other mixed lights, and to reflect or transmit other portions. The resulting color-effect is the impression made upon the retina by the unabsorbed rays. If the unabsorbed rays are reflected the object is colored and opaque; if transmitted the object is colored and transparent. Those which transmit or reflect all the colors of the spectrum are white; those which reflect or transmit none are black. The various tints in nature are dependent upon the greater or less extent to which objects reflect or transmit some colors and absorb others. Hence, objects have no color of their own. The impression made upon the retina is referred to the cause that produced it, and we attribute to external objects qualities that in reality do not belong to them, but which are merely the result of changes in the cerebral cortex.

> " 'Tis mind alone that sees and hears;
> All things beside are deaf and blind."[20]

Color, therefore, is merely an expression of impressions received, and may change with the nature of the incident light. To the man who wears dark-green spectacles all red objects appear black, because the red rays are absorbed by the green glasses and there are no rays remaining to affect the eye. The color of the costumes of actors may be changed at will by flooding them with a powerful calcium light, before which is placed a glass of the desired tint.

SENSITIVENESS OF THE RETINA TO COLOR.

The time necessary for the retina to respond to color-stimuli depends upon the strength of the color-vibrations. Thus, Catell has shown that with a unit of 0.001 second the average length of time necessary for the unfatigued eye to recognize a few of the most important colors under strong illumination equalled 0.82 second for orange, 0.96 second for yellow, 1.21 seconds for blue, 1.28 seconds for red, 1.42 seconds for green, and 2.32 seconds for violet.[21] Again, some colors are recognized at a greater distance than others, or, what amounts to the same thing, colors differ as to the amount of surface exposure to be recognized at a given distance. Oliver[22] "found that red required $2\frac{2}{3}$ millimetres exposure to be recognized at 5 metres distance; yellow, a slightly increased area; blue, $8\frac{3}{4}$ millimetres; green, $10\frac{3}{4}$ millimetres; and violet, $22\frac{3}{4}$ millimetres. In all these experiments Oliver found that the colors pass through different phases of faulty naming before being properly designated. Green almost invariably is termed whitish and bluish; red, whitish; orange, salmon color; blue, dirty white; yellow, whitish and lemon color; and violet, yellow or even pink, after being termed dirty gray."

CHAPTER IV.

THEORIES OF COLOR-PERCEPTION AND COLOR-BLINDNESS.

From time to time various theories have been advanced to account for the phenomena of color-perception and color-blindness. Each have their adherents, but it cannot be said that any one of them fully explains the phenomena in question. Still, it will be necessary, for a proper understanding of the subject, to give a description of those theories which have received the indorsement of men high in authority, particularly as upon them are based the many tests for the detection of color-blindness.

Young-Helmholtz Theory.

The original theory of Thomas Young (1807) supposes the retina to contain three sets of color-perceiving elements, corresponding to the fundamental colors red, green, and violet, and regards all other colors as varying mixtures of the fundamental sensations. Helmholtz modified this hypothesis by suggesting that every kind of light excites the red, green, and violet perceiving elements at the same time, but with different degrees of intensity. (See Fig. 11.) The three curves represent the excitability of the red, green, and violet perceptive elements to solar light; the colors of the spectrum are placed along the horizontal line, beginning with red (R) and ending with violet (V). It is thus seen that the pure red of the spectrum strongly excites the retinal

elements sensitive to red, to a less degree the elements to green, and still less the elements sensitive to violet. We thus get a sensation of red because the elements reacting to red receive the greatest excitation. Orange light strongly excites the elements sensitive to red and to a less degree the green; resulting sensation, orange. Pure yellow light strongly excites the elements sensitive to red and green, while having little action on the elements sensitive to violet. From this almost equal mixture of red and green arises the sensation of yellow. Green light strongly excites the elements sensitive to green and about equally, but to a much less degree, the

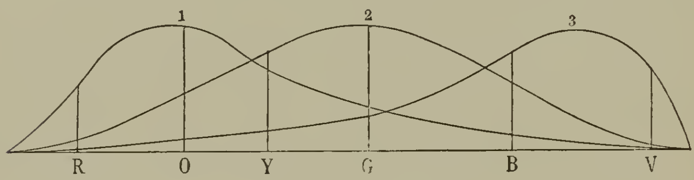


Fig. 11.

elements sensitive to red and violet; hence the sensation of green. Pure blue light strongly excites the elements sensitive to green and violet, and but slightly the elements sensitive to red; resulting sensation, blue. Violet light strongly excites the elements sensitive to violet, but has little action on the red and green elements; hence the sensation of violet. When the elements sensitive to red, green, and violet are excited simultaneously to the same degree, the resulting sensation is white. A glance at Fig. 11 shows that no color of the spectrum is fully saturated, for the reason that it always contains more or less of the other two primary colors. Yellow and blue are the most luminous colors of the

spectrum, because the elements of two of the primary colors are excited to a high degree, while the elements sensitive to the other are excited to a considerable degree.

RED-BLINDNESS.

According to the Young-Helmholtz theory blindness to red is due to the absence or paralysis of the organs perceiving red (Fig. 12). Red-blindness has, then, but two fundamental colors,—green and violet. According to Helmholtz, "spectral red, which feebly excites the perceptive organs of green and scarcely at all those of violet, must consequently appear to the red-blind a saturated green of a feeble intensity, more saturated than normal green, into which a sensible portion of the other primitive colors enters. Feebly-luminous red, which affects the perceptive organs of red in a normal eye sufficiently, does not, on the other hand, sufficiently excite the perceptive organs of green in the red-blind, and it, therefore, seems to them black. Spectral yellow seems to them a green saturated and intensely luminous, and, as it constitutes the precisely saturated and very intense shade of that color, it can be understood how the red-blind select the name of that color and call all those tints that are properly speaking green, yellow. Green shows, as compared with the preceding colors, a more

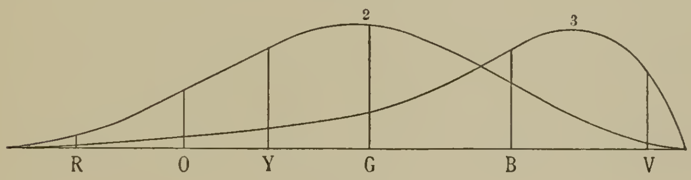


FIG. 12.

sensible addition of the other primitive colors; it then appears, consequently, like a more intense but whitish shade of the same color as yellow and red. The greatest intensity of light in the spectrum, according to Seebeck's observations, does not appear to the red-blind to be in the yellow region, as it does to the normal eye, but rather in that of the blue-green. In reality, if the excitation of the perceptive organs of green, as it was necessary to assume, is strongest for green, the maximum of the total excitation of the red-blind must be found slightly toward the blue side, because the excitation of the organ perceiving violet is then increased. The white of the red-blind is naturally a combination of their two primitive colors in a determinate proportion,—a combination which appears blue-gray to the normal sight; this is why they regard as gray the spectral transition colors from green to blue. Then the other color of the spectrum, which they call blue, preponderates, because indigo-blue, though somewhat whitish according to their chromatic sense, is to them, owing to its intensity, a more evident representative of that color than violet."

It is clear from the above that a red-blind individual cannot discriminate between red and green, because these colors excite one and the same element.

GREEN-BLINDNESS.

According to the theory, blindness to green is due to the absence or paralysis of the organs perceiving green (Fig. 13). The green-blind has therefore but two fundamental colors; that is, red and violet. According to Holmgren, "The spectral red, which strongly excites the perceptive organs of red, and but very faintly those of

violet, must therefore appear to the green-blind as an extremely saturated red, but of a light somewhat less intense than the normal red, which is comparatively more yellowish, as green forms a part of it. The spectral orange is again a very saturated red, but much more luminous. Yellow is undoubtedly a more intensely luminous red than the spectral red, but, on the other hand, more whitish, because a sensible portion of the other primitive color enters into it. Green, with its shades inclining to yellow and blue, ought, correctly speaking, to be a saturated purple and with a mean intensity of light; but it is the white (gray) of the green-

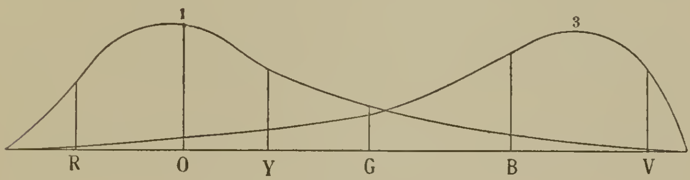


FIG. 13.

blind, for it is composed of almost equal parts of the two primitive colors. The blue is an intense violet, but a little less saturated than indigo, which is more strongly luminous and more saturated. Violet is a little less intense, but more saturated than normal violet. The tints most luminous and at the same time most saturated, which must constitute the types of the primitive colors of the green-blind, are orange or its immediate neighbor in the spectrum (red) and indigo-blue.

"Now, orange is a color which, in ordinary language, especially among the uncultivated and unpracticed, is indiscriminately called red and yellow; this fact explains why the green-blind denominate their first fun-

damental color sometimes 'red' and sometimes 'yellow.' In green-blindness the same organ is also found affected by spectral red and green light. Red and green are then perceived by the green-blind in the same way, or, in other words, are to them, in fact, exactly the same color. In cases where they succeed in distinguishing them, it is by the aid of the intensity of the light; but the opposite of what occurs in the case of the red-blind. A green tint, which to the green-blind must appear exactly like a red one, to a normal sense of color must be sensibly more luminous than red."

VIOLET-BLINDNESS

"is due, according to the theory, to the absence or paralysis of the elements perceiving violet. (Fig. 14.)

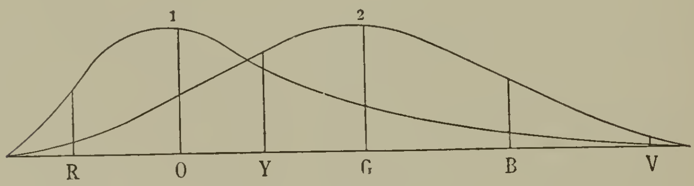


FIG. 14.

The two primitive colors of the violet-blind are then red and green. The red is a purer red color (not yellowish) than normal red, but still less saturated; the more it inclines toward orange the more strongly luminous it is, but is at the same time less saturated, more whitish. The yellow is, as it were, a combination of almost equal proportions of the fundamental colors that form white. Green is a strongly luminous but whitish green, which intending toward the blue, becomes more and more saturated; so that greenish blue must be the type of these

hues. The blue is a green of moderate luminosity and strongly saturated, and violet is green very feebly luminous, but also saturated in a much higher degree than the normal. A violet strongly luminous is sufficient to induce this green, but a feeble violet, although very sensible to the normal eye, is black to the color-blind in question. It is plain that the violet-blind, whose primitive colors are red and green, do not confuse these colors. This kind of blindness, from the experiments made so far, must be very rare."[23]

Hering's Theory.

Hering's theory of colors is based upon an analysis of color-sensations. All but four pure colors—red, green, blue, and yellow—excite in us a mixed sensation. Thus, some shades of green give us an impression of a mixture of green and yellow, others of a mixture of green and blue; purple is readily seen to be a mixture of red and blue, and orange of red and yellow. Still, among the various shades of color, we are able to pick out a certain tint of red, green, blue, and yellow, which excite in us a simple, unmixed sensation. They are called primary colors, and form two pairs, namely, red and green and yellow and blue. The two colors of each pair stand in an antagonistic relation to each other and exclude each other. In other words, if the two colors of a pair fall upon the same portion of the retina at the same time, the resulting sensation is of that color which is in excess, but never of both together. If they are mixed in certain proportions so that they neutralize each other, the resulting sensation is white (gray); hence they are called *complementary* colors.

According to Hering's theory, white and colored light produce chemical changes in the retina or in the visual substances which are present in the retina. The visual substances are of three kinds,—the white-black, the red-green, and the blue-yellow. The sensations of light and color are the result of the decomposition or dissimilation and regeneration or assimilation of the visual substances. The sensation of white depends upon the dissimilation of the white-black substance, while the sensation of darkness, or absence of light, depends upon the process of assimilation. The red-green and blue-yellow substances are not altered by every kind of light, but only by light of corresponding colors. In the case of the red-green and blue-yellow substances, it is not known which color-sensation implies assimilation and which dissimilation. According to Hering's theory, *color-blindness* is due to the absence of one or both of the colored visual substances. If both are absent the blindness is total, and all sensations of light are dependent upon the reaction of the white-black substance; hence, colors appear white of different degrees of luminosity. Blue-yellow blindness, denoting an absence of the blue-yellow visual substance, is rarely observed. Red-green blindness, in which the red-green visual substance is wanting, is quite common, and corresponds to the red-blind and green-blind of Helmholtz. To the red-green blind red and green appear white (gray), and the only colors seen in the spectrum are yellow and blue, between which is a neutral gray space corresponding to the green.[24]

Preyer's Theory

According to Preyer's theory the sense of color has developed from the sense of temperature, and is to be conceived as an extremely refined sense of temperature restricted to a most sensitive expansion of nerves,—namely, that of the retina. Color-perceptions vary only in intensity and quality. Intensity or brightness depends upon the degree of the excitation; the quality, upon the frequency of the exciting vibrations. All rays of light with a wave-length considerably greater than 0.0000546 of an inch furnish warm colors; all those with a wave-length considerably smaller, cold colors. In accordance therewith, the spectrum is divided into a warm and a cold half, which are opposed to each other. Every optic-nerve fibre ends in the retina in two cones, one of which is excited only by warm-colored, the other only by cold-colored light-rays; these excitations are received by the ganglion-cell of the retina, which transmits to the brain either the former or the latter, but never both together. In the normal eye the cones are present in even proportion, and they are so arranged that the warm cones, sensitive to red and yellow, are at equal distances from each other and from the cold cones, sensitive to green and blue; so that even in the smallest retinal image all color-excitations may be present. All color-perceptions are only affected by simultaneous excitation of the two pairs of cones. If the excitation with any one color increase, it becomes brighter, whitish, and eventually white; if it decrease, the color becomes dark and finally black. If the red and green cones, complementary couples, are excited simultaneously and in equal intensity, the nerve-undulations produced by the two kinds of ether-vibrations are propagated separately as far as the peripheral gangli-

onic cells; but thereafter, as the one nerve-fibre cannot at one time be excited in a twofold manner, neither of them produces any effect in the central organ. Although no color is perceived, the vibrations of the nerve-substance, if strong enough, cause an increase in the excitation proper of the retina,—*i.e.*, a colorless or white sensation.[25]

Correlation Theory.

This theory as expounded by Oliver is as follows: "Accepting, as we must, the Huygenian hypothesis of the imponderables, and that the peripheral portion of the human visual apparatus is adapted to the receipt of undulations equivalent to those existent between the extremes of natural color-vibrations, we are brought to a third assertion, that as all natural imponderable stimuli are the resultants of a mere difference in the number of vibrations of one and the same ether, the organs for the receipt of the different varieties must be but analogues and modifications of each other. Therefore, the most rational theory that can be brought forward is that color-perception takes place in each and every optic-nerve filament, and consists in the passive separation of a specific nerve-energy equal to the exposed natural color, from a supposed energy-equivalent resident in the nerve-tip, by an active chemico-vital process of the impinging natural vibration upon the sensitized optic nerve-tip; the separated energy being transmitted to the color-centre, where it is recognized; the healthy nerve-tip returning to its energy-equivalent the moment the specific energy, separated by the received natural vibration, has been forwarded for recognition, when it is again ready to receive any other natural color-vibration that may be cast upon it."

Typical color-blindness, according to Preyer's theory, is based upon a permanent displacement of the point of indifference for color-temperature. In red-green blindness all the warm-colored cones are only yellow-perceiving, the cold-colored cones only blue-perceiving; hence the blue-yellow spectrum. In blue-yellow blindness all the warm-colored cones are only red-perceiving and the cold-colored ones only green-perceiving; hence the red-green spectrum.

CHAPTER V.

COLOR-BLINDNESS.

Classification.

We may conveniently arrange cases of color-blindness under two heads: *total* and *partial*.

1. *Total color-blindness*, in which the color-sense is entirely wanting and where all objects appear gray, differing only in intensity. Persons suffering from this defect see the world as if it were an engraving or drawing in black and white. Total absence of color-perception is rarely met with, and, in fact, its existence is denied by some observers.

From two personal cases, added to the three cases of Landolt, Querenghi[26] concludes as follows regarding total color-blindness: "In the five cases there was considerable reduction of visual acuity, though rarely falling below one-tenth. In four of the cases nystagmus was present; three patients had intense photophobia, especially when exposed to a bright light; spectral and dark red produced in all cases a sensation equal to black, the other colors being recognized as achromatic light, their intensity varying with the nature of the color and its degree of saturation. Further, after white, yellow gives the most intense sensation of light, and in the cases that presented on the red side a reduction in the perception of the spectrum (three cases) the band of greatest light was displaced toward the green, whilst the patients to whom the whole spectrum was light indicated the line of greatest clearness in the yellow."

2. *Partial color-blindness*, in which the color-sense is imperfectly developed for one of the three primary colors,—red, green, or violet,—as advocated by the Young-Helmholtz school; or for red and green or blue and yellow, according to Hering's hypothesis. Blindness to red or green or red-green is the form of the defect most frequently observed, and may be *complete*, *incomplete*, or so little removed from normal that the term *feeble chromatic sense* adequately describes the condition.

Frequency of Color-Blindness.

The earlier statistics on this subject varied to a considerable degree, owing, doubtless, to faulty methods of examination or to lack of a sufficient number of cases upon which to base reliable data. Professor Seebeck found 5 cases out of 40 boys who composed the two upper classes of a school in Germany (12.5 per cent.). Professor Prevost, of Geneva, stated that they amounted to 1 in 20 (5 per cent.). Professor Wilson found 1 color-blind out of every 17.7 persons (5.6 per cent.); Professor Favre, 1 in 10.7 persons (9.33 per cent.).

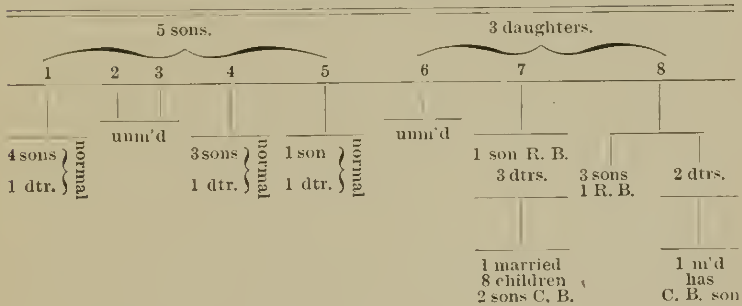
The introduction of Holmgren's improved method of testing and extensive investigations in this country and abroad have shown that the common forms (blindness to red and green) exist in about 4 per cent. of males and in about one-fourth of 1 per cent. of females. There has been much speculation as to the cause of its rarity among women. It is thought that this immunity may be accounted for by the fact that from early childhood women are engaged on work which requires a constant handling and comparison of colors. The color-sense is thus developed to a high degree, and

possibly constitutes a sexual difference which is handed down from generation to generation.

HEREDITY.

All authors agree that color-blindness is hereditary. Horner's law, that sons of daughters whose father was color-blind are most likely to be the same, is illustrated by the following case of Fontenay[27]:—

FATHER COLOR-BLIND.



An exception to this general law is Cunier's case mentioned by Jeffries[28]: A lady was color-blind; her mother and 2 sisters were the same. Her brother was free from the defect. The lady had 6 children, 1 son not color-blind and 5 daughters affected like herself. The oldest daughter had 4 children, 2 of them (girls) color-blind. The second daughter had a boy and a girl, the latter color-blind. Fourth daughter unmarried. The fifth left a boy myopic, but not color-blind. From a large experience Holmgren deduces the following: 1. Color-blindness is hereditary and attached to certain families. 2. It may not be found in one generation, but re-appears in the next. 3. All the children will not be affected, the girls especially escaping. 4. When

several children are affected it is traceable to the mother. 5. The kind and degree will be the same for all the cases in a family.

Heredity is thus seen to be an important factor in the production of color-blindness, and, as would be natural to expect, it is frequently observed among sects or races where intermarriages are frequent. Most of the early cases of color-blindness were found among the Quakers, and Mr. Carter tells us that, in England, it is more common among Jews than among the general population.

Complexion.

Seebeck, Magnus, Cohn, and Fontenay noticed that a large proportion of the color-blind had light complexions, light hair and eyes. Later investigation proves that the complexion has no bearing on the proportion of color-blind. The association was probably only accidental, and arose from the fact that, in the countries where the above tests were made, the prevailing national complexion was light.

Peculiar Look of the Color-Blind.

A peculiar look of the color-blind was first noticed by Professor Wilson, of Edinburgh, and described by him as "an absent, anxious glance," as "a startled, restless look," and as "an eager, prying, aimless air." Dr. B. Joy Jeffries[29] has observed this peculiar look in a number of color-blind. He describes it as "a certain liquid look, as if the eyes were slightly suffused. . . It gives the color-blind person the appearance of not listening or not being interested in what is said to him." Professor Wartmann remarks, "I have observed, in the case of

'Daltonians' whose eyes are brown, a golden lustre of a peculiar tint, when the eye is viewed under an incidence of some obliquity."

Monocular Color-Blindness.

Congenital color-blindness involving one eye only is an extremely rare condition. Indeed, the possibility of such a defect was denied until Becker published a case and gave a full and accurate description of the disease. His patient was a girl of 17, in whose family there were color-blind males. Cases of this kind are of great value from a scientific stand-point, as it is thus possible to compare the normal with the abnormal color-sensations. The results obtained in this manner fully agree with preconceived ideas.

According to Hering: "1. All colors appear to the affected eye less saturated,—*i.e.*, have a more white or grayish tone. 2. Yellow and blue suffer no change of tone, but appear less saturated. 3. Green and red near in tone to the respective original colors appear colorless. 4. The intermediate colors—spectral red, orange, yellowish green, and a violet of moderate saturation—lose their red and green tone and appear as a pale whitish or grayish blue and yellow."[30]

The possible existence of monocular color-blindness should be remembered, and surgeons should make it a rule to test each eye separately.

Education and Social Condition.

Fontenay[31] (Denmark) examined 1001 educated people, and found 31 color-blind (3.09 per cent.). Among 3491 uneducated persons he found 134 color-

blind (3.87 per cent.). But the number of persons examined in the higher walks of life has not been sufficient to permit of a positive statement. Educated people, from their surroundings, are more familiar with colors, and give intelligent answers when examined; so that we are less liable to mistake color-ignorance for color-blindness. We do know, however, that education and practice tend to develop the normal color-sense to a high degree. Thus, boys and men of the lower classes find great difficulty in recognizing the spectral colors, while those whose color-sense has been educated can distinguish some 2000 or 3000 tints, and M. Chevreul established 14,420.

Although education may improve a normal color-sense, no amount of study will change for the better a color-sense which is deficient or wanting.

Curability of Color-Blindness.

It is now definitely decided that congenital color-blindness is incurable. The wide-spread belief in its curability originated from the investigations of Dr. Favre, of Lyons, which seemed to show that the defect was cured by exercising the chromatic sense. He distributed among the school-teachers packages of colored worsted, each containing three shades of red, orange, yellow, green, blue, indigo, and violet. The children were examined one by one and required to name the colors. Those who made mistakes were subjected to a daily drill until they were able to name the colors correctly. In this manner 1002 boys between the ages of 4 and 15 were examined, of which 218 were reported as having a defective color-sense and nearly all were cured

by the daily exercise with colors. The deductions made from this investigation are valueless, because the method employed confused color-ignorance with color-blindness. The mere fact that a large number of the boys were unable to give the color-names correctly was no proof of a defective color-sense, for we know that school-boys, as a rule, know little or nothing about colors or color-names. It therefore becomes necessary to prove the existence of color-blindness before it can be claimed that it has been cured by treatment. That there were several color-blind children among the number examined is shown by the statement of one of the teachers, who said: "I sometimes despaired of curing one child, 6½ years of age, who, after sixty-five exercises, could not tell me a single color without hesitation. Eleven exercises more, however, cured this unexampled Daltonian, who began by first distinguishing green and finished by not always calling red yellow when shown him."[32] Professor Holmgren[33] says: "It is a significant fact that individuals who have themselves discovered their own chromatic blindness, and have been very much interested in it, having reflected and experimented, and consequently exercised themselves much in colors, have nevertheless retained their anomalous perception, such as it was in the beginning, for many years; indeed, as long as they lived. Such was the case with Harris, who himself discovered his defect at the age of 4 years and studied it with much interest, but never succeeded in correcting it. Milne was found by Wilson to be as color-blind at Edinburgh in 1854 as he was thirty years before, when Combe examined him. Such was also the case with Professor N., examined twenty years before by Sir David Brewster.

But such was especially Dalton's case, who has thrown much light upon the subject. No one will deny that if exercise in colors can cure chromatic blindness Dalton would have been cured, and yet it must be acknowledged that at the meeting of the British Association at Oxford, in 1832, he then compared a scarlet red to the leaves of trees, proving him to be as color-blind as in 1792, the date of the discovery of his color-blindness, and, as far as his friends could observe, he continued so to the end of his life (1844)."

Palliation of Color-Blindness.

The first to suggest a palliative remedy for color-blindness was Seebeck, who found that color-blind people were able to distinguish by lamplight colors which appeared the same by daylight. Benefit was also obtained by looking through colored glass. He therefore proposed the use of colored spectacles, but what color he advised is not known.

As most color-blind people are unable to distinguish between red and green, theoretically, a pair of spectacles containing a red and a green lens should be of some service. The red lens would cut off most of the green rays and the green lens the red rays; hence red and green would be easily distinguishable by a difference in the intensity of the colors. Practically, however, very little benefit is obtained, and the glasses are so conspicuous that no one would be willing to wear them. From the fact that the color-blind distinguish colors better by lamplight, Wilson proposed the use of yellow or pale-orange glasses. Most of his patients received no benefit, but two of them were able to distinguish between

red and green, which before was impossible except by lamplight. Professor Delboeuf, who is color-blind, found that by looking through a solution of fuchsin he could distinguish between red and green, and even imagined that the solution had curative properties. Extended trial, however, proves it of little more value than the pale-orange glasses before mentioned.

Color-Blindness in Every-Day Life.

One of the most remarkable peculiarities of color-blindness is its tendency to conceal itself not only from the community at large, but from the defective individuals themselves. Although statistics prove that one person out of twenty-five is color-blind, how many of us know of a single case existing among our friends and acquaintances? It is only when a systematic search is made among all classes of society that the frequency of the defect becomes apparent. How, then, does the ordinary case of color-blindness—that is, blindness to red or green—escape detection?

It is not to be supposed that such an individual is blind to all colors; on the contrary, although blind to one fundamental color, he still retains two; so that, in many respects, his color-sensations do not differ from the normal. Those colors which he never mistakes, such as yellow and blue, are named freely, and if he occasionally confuse red and green his friends put it down to carelessness or lack of training, but never for a moment suspect the real nature of his defect. Another means by which the color-blind escape detection is by the use of color-names. From childhood they constantly hear the color-names of various objects and use them correctly

when occasion demands. The color-blind may see very little difference between the color of a brick house and that of the lawn which surrounds it, and yet they always speak of the former as red and the latter as green. Past mistakes have taught them to be cautious, and, as a matter of habit, they avoid giving the color-name of an object of which they are not familiar. Dr. Jeffries[34] says: "The color-blind who are quick-witted enough to discover early that something is wrong with their vision by the smiles of their listeners when they mention this or that object by color are equally quick-witted in avoiding so doing. They have found that there are names of certain attributes they cannot comprehend, and hence must let alone. They learn also what we forget,—that so many objects of every-day life always have the same color, as red tiles or bricks, and the color-names of these they use with freedom; whilst they often, even unconsciously, are cautious not to name the color of a new object till they have heard it applied, after which it is a mere matter of memory stimulated by a consciousness of defect."

When the color-blind are placed in positions where a familiarity with colors is a necessity, curious blunders are often made, which, although not dangerous to life, may cause much confusion and annoyance. Mr. Carter[35] mentions "an instance of a clerk in a government office, whose duty it was to check certain entries, in relation to their subject-matter, with ink of one or of another color, and whose accuracy was dependent upon the order in which his ink-bottles were ranged in front of him. This order having been accidentally disturbed, great confusion was produced by his mistakes, and it was a long time

before these mistakes were satisfactorily accounted for. An official of the Prussian post-office, again, who was accustomed to sell stamps of different values and colors, was frequently wrong in his cash, his errors being as often against himself as in his favor, so as to exclude any suspicion of dishonesty. His seeming carelessness was at last explained by the discovery of his color-blindness, and he was relieved of a duty which it was impossible for him to discharge without falling into error."

Practical Advantage of Color-Blindness.

Although color-blindness is a hindrance in certain occupations, it has its compensations. Thus, one patient says: "I see objects at a greater distance and more distinctly in the dark than any one I recollect to have met with; this I discovered many years before I was aware of my defective error in colors."[36]

A color-blind engraver, who was a patient of Wilson, states that his defective vision is, to a certain extent, useful and valuable. "When I look at a picture I see it only in white and black, or light and shade; and any want of harmony in the coloring of a picture is immediately made manifest by a corresponding discord in the arrangement of its light or shade, or, as artists term it, the effect. I find, at times, many of my brother-engravers in doubt how to translate certain colors of pictures, which to me are matters of decided certainty and ease."[37] Dr. Little[38] reports a similar case. He says: "In one of the largest publishing houses of Philadelphia, one of the firm requested me to test a gentleman in the establishment who had trouble with colors. The gentleman examined presented the condition of

red-blindness. I told him that he would make a good engraver, when the member of the firm announced: 'That is what he is good at, and is our authority on the subject.'"

It is thus seen that the color-blind are peculiarly fitted to excel in the art of engraving, and the advantages of this profession should be explained to those who are debarred from other occupations by reason of their congenital defect.

Dangers of Color-Blindness.

Color mistakes, such as were made by the government clerk and post-office official, are of little importance when compared with those liable to be committed in occupations where colored signals are employed and where human life is in jeopardy. If we visit one of the great railroad terminal stations at night and view the intricate maze of red, green, blue, and white signals, we at once realize how much depends upon the perfect color-sense of the engineer. If he be color-blind the red and green signals appear to be of the same color and he can only distinguish one as lighter or darker than the other; but a small amount of smoke, fog, snow, and ice destroys this difference and the traveler is at the mercy of his conjecture. That this is a real danger is attested by the many disastrous accidents which have occurred in this country and abroad, and which have been proved to be the result of color-blindness. Notwithstanding all that has been written on this subject, railroad managers still continue to employ men without testing the color-sense. Strange as it may appear, the color-blind employé may perform his duties satisfactorily for many years with-

out causing an accident, and, indeed, without becoming aware of his chromatic defect. I personally tested an engineer, blind to red, who had been in active service for thirty years, and who, when apprised of his condition, refused to believe it and insisted on a re-examination. As Holmgren[39] says: "A number of them, far from being willing to acknowledge, even after the examination, the existence of such a defect, urgently demanded a new trial,—even six or seven,—offering all kinds of pretexts to account for their repeated failures. They all agree in declaring that they have excellent sight; that they have never had the least difficulty in distinguishing signals, though they have been employed for a long time and in the most important positions, and had never made the slightest mistake." How, then, are we to explain the remarkable fact that men who cannot distinguish red from green may run an engine for a long period of years without causing an accident? Mr. Carter, in his interesting article on "Color-Vision and Color-Blindness," says: "A locomotive, as we all know, is under the charge of two men,—the driver and the fireman. In a staff of 1000 of each, allotted to 1000 locomotives, we should expect, in the absence of any efficient method of examination, to find 40 color-blind drivers and 40 color-blind firemen. The chances would be 1 in 25 that either the driver or the fireman on any particular engine would be color-blind; they would be 1 in 625 that both would be color-blind. These figures appear to show a greater risk of accident than we find realized in actual working, and it is manifest that there are compensations to be taken into account. In the first place, the term 'color-blind' is

itself in some degree misleading, for it must be remembered that the signals to which the color-blind person is said to be 'blind' are not invisible to him. To the red-blind the red light is a less luminous green; to the green-blind the green light is a less luminous red. The danger arises because the apparent differences are not sufficiently characteristic to lead to certain and prompt identification in all states of illumination and of atmosphere.

"It must be admitted, therefore, that a color-blind driver may be at work for a long time without mistakes; and it is probable, knowing, as he must, that the differences between different signal-lights appear to him to be only trivial, that he will exercise extreme caution. Then it must be remembered that lights never appear to an engine-driver in unexpected places. Before being intrusted with a train he is taken over the line and is shown the precise position of every light. If a light did not appear where it was due, he would naturally ask his fireman to aid in the lookout. It must be also remembered that to overrun a danger-signal does not of necessity imply a collision. A driver may overrun the signal, and after doing so may see a train or other obstruction on the line, and may stop in time to avoid an accident. In such a case he would probably be reported and fined for overrunning the signal; and if the same thing occurred again he would be dismissed for his assumed carelessness, probably with no suspicion of his defect. Color-blind firemen are unquestionably thus driven out of the service by the complaints of their drivers; and none but railway officials know how many cases of overrunning signals, followed by disputes as to

what the signals actually were, occur in the course of a year's work."

Although accidents may be avoided by a combination of circumstances such as have just been mentioned, the fact remains that collisions attended with loss of life and damage to property are of frequent occurrence, and there is reason to suppose that color-blindness is the predominant, though unsuspected, factor in many cases. It is therefore urgent that the subsequent investigation of an accident should include a strict inquiry as to the color-sense of each and every member of the crew or crews concerned. Furthermore, the interest of the public, employés, and railroad company demands that the color-sense of employés should be under official control, and that all applicants should be required to submit to a thorough test before being taken into the service. It is in the public interest, because it has a right to demand the adoption of every means to lessen the risks of travel; in the interest of the color-blind employés, because they are often the first to suffer in the disasters which their defects have produced; and in the interest of the railroad company, because it has to repair the damage and satisfy the claims of the injured.

The Adoption of a New System of Signals.

According to the present system of signaling three colors are used,—*i.e.* red, danger; green, caution; and white (yellow), a clear track,—or just those colors which the red-green blind fail to distinguish with any certainty. In order to overcome this difficulty without discharging the color-blind, Wilson proposed the use of *other colors*, or the adoption of a new system of signals, which should

be based upon *form*, *motion*, and *number*. This suggestion would seem to offer an easy solution of the problem, but experience has shown that such changes are not practicable.

Other Colors.—The red-green blind are only able to distinctly define two colors of the spectrum; so that any system of color-signals to be adapted to their condition must be based upon two colors. This, in itself, is a serious objection, and would hardly satisfy the demands of railroad traffic. But suppose it were possible to get along with two signal colors; we should then naturally select yellow and blue as the most suitable, because they are never mistaken by the red-green blind. Yellow and blue flags would answer admirably for day signaling, and, in fact, almost any colors would suffice for day use, because there are many other means by which the engineer is apprized of approaching danger. At night, however, signals are of the greatest importance, and should be recognizable at a great distance, for they alone can be depended upon for guidance and warning. Unfortunately, yellow and blue lights are not suitable for this purpose, because the yellow light is much more luminous than the blue. The dangers of accident would be enhanced because the normal-sighted would be placed in the same condition as the color-blind,—*i.e.*, they could only distinguish between the night-signals by the intensity of the light.

Form, Motion, Number.—Instead of colored lights, it has been proposed to substitute, as signals, large, brilliant surfaces, arranged in different ways; several small lights grouped in different positions; lights differing in value as signals according to their number; or a row of lights

arranged in a perpendicular or horizontal manner. There are many practical objections to such a system. In the first place, signals must be portable and ready for use at all times and in all places,—for instance, on the front of the engine; at the rear of the train; in case of delay or accident, the rear brakeman must go back and signal any approaching train. It is at once apparent that the system of signals which we are now considering would not be adapted to such use. Again, a system of signals based upon form would not be recognized at a sufficient distance by those who had any imperfection of vision, and, as the number of such far exceeds the number of color-blind, the change would make matters worse instead of better. It is thus seen that there are serious objections to any system of signals based upon the principles just mentioned, and that, thus far, nothing has been offered which is an improvement upon the system in general use at the present day.

CHAPTER VI.

METHODS FOR DETECTING COLOR-BLINDNESS. SELECTION TESTS.

The methods for detecting color-blindness may be arranged in three principal groups: (1) selection tests; (2) pseudo-isochromatic tests; (3) contrast tests. Among the first are Holmgren's worsteds, Thomson's stick, and Oliver's test. Among the second are Stilling's colored figures or letters on a colored ground, Mauthner's powders, and Donders's patterns. Among the third are colored shadows, Meyers's and Pflüger's tissue-paper tests, and the contrast experiment of Ragona Scina. Then there are others, which may be used separately or in combination, such as the spectral apparatus, the polariscope, Maxwell's disc, and various arrangements with colored glass. It might well be supposed that such a wealth of tests would be superfluous; but experience has shown that the detection of color-blindness is difficult, and that, as we sometimes have cases of simulation to deal with, the examiner must be prepared to use a variety of tests.

The ordinary observer naturally supposes that all that is required to test the chromatic sense is to display the flags and lanterns used as signals and demand the name of the color exposed. Indeed, this method seems so simple and so ample that it is often practiced even by the physician, and is the loop-hole through which many color-blind have escaped detection. As Mr. Carter says, "To be effectual, such a test must be applied in different states of the atmosphere, with colored glasses of various

tints, with various degrees of illumination, and with the objects at various distances; so that much time would be required in order to exhaust all the conditions under which railway signals may present themselves. This being done, the examinee must be either right or wrong each time. He has always an even chance of being right, and it would be an insoluble problem to discover how many correct answers were due to accident, or how many incorrect ones might be attributed to nervousness or to confusion of names. We must remember that what is required is to detect a color-blind person against his will; and to ascertain, not whether he describes a given signal rightly or wrongly on a particular occasion. but whether he can safely be trusted to distinguish correctly between signals on all occasions. We want. in short, to ascertain the state of his color-vision generally; and hence to infer his fitness or unfitness to discharge the duties of a particular occupation."[40] We can only accurately determine how a man sees colors by making him pick out and place together those colors which appear to him to be the same. This principle of testing is followed in the selection tests, which have been found to be the most practical and certain of all.

SELECTION TESTS.

HOLMGREN'S METHOD.

After a study of Seebeck's method, which requires the individual to arrange about three hundred pieces of colored paper, Holmgren introduced a modified method. which, while being just as reliable, shortened the time necessary to make an examination from an hour to a

minute. It consists in asking the candidate to make matches to certain test colors, which are placed to one side of the general heap of match and confusion colors. Holmgren discarded the use of colored paper, glass, silk, powders, wafers, wood, etc., and adopted colored worsted for the following reasons: It is not expensive and can be obtained at any time and in any desired color or shade. The worsted is equally colored on all sides, does not reflect the light, is soft and easily handled. The worsted is always ready for use and after the examination can be packed into a small space without damage. The colors to be selected are red, orange, yellow, yellow-green, pure green, blue-green, blue, violet, purple, pink, brown, gray,—several shades of each color and at least five gradations of each tint from the deepest to the lightest. The pale-gray shades of brown, yellow, red, and pink must especially be well represented. In all there will be about one hundred and fifty skeins, which should be of the same size and general appearance. Such a large number of skeins seems uncalled for, but any lesser assortment restricts the choice of the examined and makes the detection of color-defect much more difficult. Prof. Holmgren selected *light green* and *rose* as the sample test colors, and it will be of interest to know his reasons for so doing. He says: "Experience, as well as the application of the Young-Helmholtz theory to the facts, teaches us that more than one color may serve as the sample in searching for a sure and definite characteristic of defective chromatic sensation. All colors do not, however, meet this equally well. The faculty possessed by the eye of distinguishing colors and that of defining the degrees of light and

color (of saturation) are relatively very different; but these special faculties have this in common: that they have their maximum activity in a certain intermediary region of absolute intensity of light and their minimum at the two limits of this region. Just as we experience the most difficulty in distinguishing between the shades of intensity of light by a very feeble or very strong illumination, so it is difficult for us to distinguish colors slightly or strongly luminons, or the deepest and the lightest. It is, therefore, necessary to select, as a suitable color for discovering a feeble chromatic sense, either the lightest or darkest shades. The well-defined kinds and degrees of a defective chromatic sense confound only colors of mean intensity. I have selected, to determine whether the chromatic sense is or is not defective, a light-green (dark-green may be also used), because green, according to the theory, is the whitest of the colors of the spectrum, and consequently is most easily confused with gray. For the diagnosis of the especial kinds of partial color-blindness I have selected purple (rose); that is, the whole group of colors in which red (orange) and violet (blue) are combined in nearly equal proportions,—at least, in such proportions that no one sufficiently preponderates over the other, to the normal sense, so as to give its name to the combination. This is the reason for this choice. Purple occupies a singular position among colors; although it is a combination, it is, we know, a color as well saturated as the colors of the spectrum, and might be, from this point of view, classed with them, although it is not found in the spectrum. In fact, it has been regarded as the eighth color of the spectrum, closing the circle of saturated colors.

Purple (rose) is of especial importance in the examination of the color-blind, for the reason that it forms a combination of two fundamental colors—the two extreme colors—which are never confounded with each other. In fact, from a color-blind point of view, one of two things must happen according to the theory: either it excites but one kind of perceptive organ or it excites them all. It appears, then, either like a simple color—that is to say, like one of the two colors of the combination—or like white (gray). Experiment has confirmed this hypothesis. Our sample colors, therefore, are the two complementary colors of each other,—*green* and *purple.*[41]

THE EXAMINATION.

First Test.—The worsted is placed in a confused heap on a large, plane surface, in a good light; the match skein, of *light pure green* (neither a blue nor a yellow green), is taken from the pile and laid to one side. The candidate is requested to select the other skeins most resembling it in color and place them by the side of the sample. We must explain that resemblance in every respect is not necessary, that there are no two skeins exactly alike, and that an endeavor must be made to find something similar of a lighter or darker shade. He is not to compare narrowly or to rummage much amongst the heap, but to select with his eyes and to use his hands chiefly to change the position of the selected skeins. If he does not understand, we must ourselves make the trial by searching with our own hands for the skeins. After we have shown in a practical manner what we want him to do, we must restore the whole to the pile, except the sample skein. If a large number

are to be examined, we can save time by instructing all at once, and allowing them to observe the examination of those preceding them. This assists the normal-eyed in making his selections quickly, without, on the other hand, conveying any information to the defective by which he can avoid making the characteristic mistakes of the color-blind. A person with a *normal color-sense* will pick out the lighter and darker shades of green rapidly and without hesitation. He may, perhaps, include in his choice a few green skeins inclining to yellow or blue; but this is no evidence of color-blindness, but rather of a lack of practice with colors. The *completely color-blind*, whether to red or green, will select, with or without the greens, some confusion colors,—grays, drabs, stone-colors, fawns, pinks, or yellows. The *incompletely color-blind*, or those with a *feeble chromatic sense*, will add to the selection of greens one or more light fawns or grays; or they may pick out a skein, hesitate, add it to the greens and then withdraw it, and so on.

When confusion colors have been selected, we know that the candidate is either completely or incompletely color-blind. In order to determine its nature and degree we employ a second test.

Second Test.—The worsted is mixed again and a skein of *rose* is laid to one side. The candidate is requested to pick out all the lighter and darker shades of this color. The color-blind always select deeper colors. Those who by the first test were found to have a *feeble chromatic sense* will make no mistakes in this test.

The *incompletely color-blind* will match the rose with deeper purples.

The *completely red-blind* will select blue or violet, either with or without purple.

The *completely green-blind* take green or gray, or one alone, either with or without purple.

The *violet-blind* show a strong tendency to select blue in the first test, and red and orange, either with or without purple, in the second test.

While the diagnosis of violet-blindness is difficult, it is also very rare. As we have decided the character and degree of the defect, it is not necessary to resort to the third test; but as the red skein used corresponds to the danger-signal, it may occasionally be of value in convincing the officials and other persons that the candidate is unfit for duty.

Third Test.—The sample for this test is a skein of *bright red*, to be used in the same way as the green and rose. The *red-blind* select, besides the red, green and brown shades darker than the red. The *green-blind* select green and brown shades lighter than the red. Only marked cases of color-blindness will show their defect with this test.

PRACTICAL NOTES ON TESTING.

The Relation of Examined and Examiner.—On this point Holmgren says: "The combination of the action of the eye and hands, which plays, in general, so important a part in the training and uses of the senses, is also of great consequence in this examination. An attentive examiner, especially if he have already acquired some experience, can draw important conclusions from the manner in which the other executes his task, not only and directly with regard to the nature of his chro-

matic sense, but generally as to his intelligence and character, and especially, in some cases, as to his previous training and exercise in the use of colors, and his skill in recognizing them. The examination affords us also the opportunity of making psychological observations, which contribute, in a great measure, in giving us a clear idea of the nature of the chromatic sense. A practiced surgeon can often detect color-blindness by the first gesture of the examined and make the diagnosis before the end of the trial. He can, according to the manner in which the task is performed, form a judgment of a feeble chromatic sense in instances which are proved correct by the final result. He also can and must see whether the result is erroneous simply on account of a misunderstanding or a want of intelligence, just as he can see whether the really color-blind succeeds, in a certain degree, from much previous exercise or a considerable amount of caution. In short, the method supplies us with all necessary information; so that, by an examination made with its assistance, a defective chromatic sense, no matter of what kind or in what degree, cannot escape observation. It also calls upon the examiner to watch the examined very carefully and note his every motion. Different people act very differently during the examination, for many reasons. Some submit to it without the least suspicion of their defect; others are convinced that they possess a normal sense. A few only have a consciousness or, at least, some suspicion of their defect. These last can often be recognized before the least examination by keeping behind the others, by attentively following the progress of the trial, but, if allowed, willingly remaining to the

last. Some are quick, others slow. The former approach unconsciously and boldly, the latter with over-anxiety and a certain dread."[42]

If the candidate pull over the heap of worsted without finding a skein which he is willing to place by the sample, he should be requested to step back a pace and, keeping his hands behind his back, search the pile with his eyes. As soon as he detects the skein he is looking for he may then pick it out and place it by the side of the sample. If, on the other hand, he proceed with the greatest caution, or do not even touch the worsted, we may hasten the trial by holding up one skein after the other and asking him whether it resembles the sample. If, assisted in this manner, he accept one or more colors of confusion, we should not conclude the test without calling his attention to his selection and asking if he is satisfied or if he would desire to make any change. In order to save time and secure reliable results, it will be advisable to restrict the choice in the first test to the lighter shades of green. In fact, Holmgren selected as the sample a pure pale green because the color-blind readily confound it with gray, drab, straw, and salmon color. If the candidate were allowed free choice he would prefer to select the darker and more vivid shades and avoid the lighter, where his defect would soon be discovered. As before mentioned, even the normal-eyed find great difficulty in distinguishing between the blue greens, yellow greens, and pure greens. As therefore the blue and yellow greens only serve to confuse the candidate and thus retard the examination, *Holmgren's modified test*[43] may often be of service. It consists in taking from the pile of worsted all the shades of green

except the five shades of pure green; that is, all the greens inclining to blue or yellow. It is claimed that the color-blind will surely make a mistake before he has removed the four shades of pure green remaining. Still, by thus limiting the selection, the work of the examiner is made more difficult and the cases of incomplete color-blindness or feeble chromatic sense may be overlooked. As the red-green blind never mistake yellow and blue, we may resort to another test, which is quite striking to by-standers. We request the candidate to pick out all the yellow skeins. This he does with much assurance, at the same time adding all the green skeins that have yellow in them. If he then be asked to pick out the blue skeins, he first takes the darkest shades of blue and then adds the purple skeins, because he recognizes the blue in the mixture of red and blue. In the hands of an expert Holmgren's method is perfectly reliable. The unsatisfactory results often obtained are doubtless due to a neglect of Holmgren's specific directions.

Railroad officials, deceived by the seeming simplicity of the method, often allow section foremen to conduct the examination. They receive a small stock of worsted, selected at random, and often proceed to test the color-sense by pulling out a single thread and asking the man to name the color. Even physicians often allow the candidate to critically compare the skeins, which in itself should be a sufficient indication of defect. In a report made by the committee of the British Ophthalmological Society appears the following: "Your committee becomes more and more convinced that a competent examiner is not made in a day or a month, and that even with large experience much judgment and capacity

are needful to interpret rightly the acts of the examined."

THOMSON'S STICK.

In 1880 Dr. William Thomson,[44] of Philadelphia, was invited to arrange a test for color-blindness to be used on the Pennsylvania Railroad System. After a careful study of the subject he became convinced that it would be impossible to examine personally thousands of men scattered over many hundred miles of road, and, in the absence of a sufficient number of special experts, some system was needed that could be put in force by each division superintendent acting through an intelligent employé. Furthermore, the system must be under the general supervision of the ophthalmic surgeon, who could decide all doubtful cases and thus protect the road from danger and the men from being discharged on insufficient grounds. In adapting a method to the needs of inexperienced examiners, Thomson numbered the worsteds so that the ophthalmic surgeon, although absent from the trial, could tell, from the findings of the examiner, the exact tints selected by each man. The instrument consists of two narrow, flat sticks, hinged together at one end and fastened by a catch at the other. (See Fig. 15.) The inside stick contains a row of forty hooks, to which are attached by bangles forty test skeins, arranged to be alternately match and confusion colors. The bangles are numbered in such a way that odd numbers denote match skeins, and even numbers confusion skeins. The skeins from 1 to 20 correspond to Holmgren's *first test*, and consist of various shades and tints of green alternating with confusion colors,—grays, tans, light browns, etc. The second

series, from 21 to 30, is composed of lighter and darker shades of rose alternating with blues, etc. The third series, from 31 to 40, is made up of reds alternating with browns, sages, and dark olives.

In making an examination the candidate is requested to select ten tints from the worsteds on the stick to match the light-green sample. The numbers attached to the selected tints are recorded, and if the person have a good color-sense his record will show none but odd numbers between 1 and 20; while, if he be color-

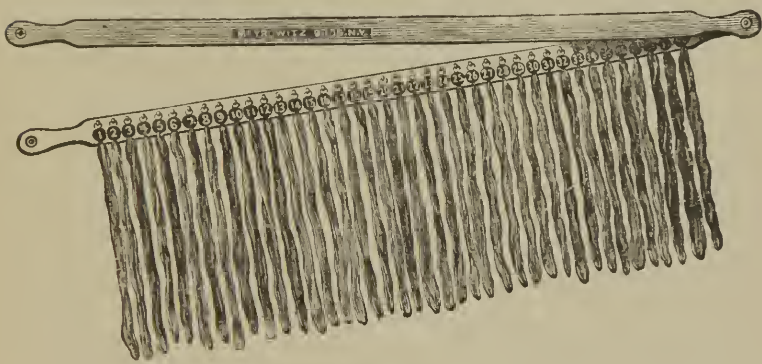


FIG. 15.—THOMSON'S STICK.

blind, the mingling of even numbers betrays his defect at a glance. In order to determine whether the defect is for red or green, the candidate is required to match the rose sample. The red-blind selects indifferently the roses and blues between 20 and 30, while the green-blind adds greens and grays. The third series, with red as the sample test, is used in the same manner and corroborates the results obtained by the green and rose tests. The record of each case is examined by the ophthalmic surgeon, and any man failing to come up to

the standard is given the benefit of a final examination at the hands of the expert. This method, together with a test for vision and hearing, was subjected to an experimental trial on the Pennsylvania Railroad. Dr. Thomson reports 1383 examinations among conductors, engineers, firemen, and brakemen; 246 men were deficient in the full acuteness of vision, 55 absolutely color-blind, and 21 defective in hearing. Commenting on the result of the color-blind test, Dr. Thomson says: "The entire number reported as defective in color-sense ($4\frac{2}{10}$ per cent.) is up to the average, as reported by the best authorities, in its percentage, but those absolutely color-blind, and hence unable to distinguish between soiled white or gray and green, or a green and red flag, are fully 4 per cent., and this proves that the instrument employed in this part of the examination has met our expectations fully."

THOMSON'S NEW WORSTED TEST (1894).

Several objections have been urged against the Thomson stick: 1. As the worsted is attached to a stick, any choice to be made by the person examined is greatly curtailed. One of the cardinal points of Holmgren's method is that the worsted must lie in a confused mass upon the table, so that the candidate in selecting his matches may have full play to exhibit his defect. 2. As the skeins are arranged in regular order, alternating match and confusion skeins, this, the distinguishing feature of the method, is liable to become known and the test thus rendered worthless. Dr. Thomson's new test seeks to overcome these objections by conforming more strictly to Holmgren's method. The test consists

of two different sets of worsteds, which must always be kept apart, not only in their corresponding part of the box, but also in testing the men. The *first set* consists of a large *green* sample skein and twenty small skeins, each marked with a bangle having a concealed number extending from one to twenty. Among these numbers the odd ones are different shades of green, while the even numbers are grays, light-browns, etc. The *second set* consists of a large *rose* sample skein and twenty small skeins which are numbered from 21 to 40. Here the odd numbers are different shades of rose color, while the ten even numbers consist of blues, greens, and grays. The worsted is to be kept from the light in the double box, one side of which is colored green and the other rose, to aid the examiner in keeping the series separate.

In testing, the worsted is taken from the green part of the box and placed upon a table in a confused mass. The candidate is requested to select ten tints to match the large green skein. When this is done, and the numbers recorded, the worsted is removed and the examiner proceeds with the second set. The red test skein of the stick with its confusion colors is omitted as unnecessary. For the use of the surgical expert, two more large test skeins have been added; one, *C*. yellow, and the other, *D*, blue. The test *C* is exposed, and the candidate is asked to match it if possible from the skeins 1 to 20. If normal in color-sense he will decline, or at the most only take the yellow-green skein; but if color-blind he will select a number of the green skeins, which should be recorded. Then use test *D*, the blue skein, and let him match it from skeins 21 to 40. If normal or green-blind he will select blues only, but if red-blind

he will pick out a series of roses, which should be recorded.[45]

OLIVER'S WORSTED TEST.

The test, as described by the author, is as follows: "A square of black muslin is placed upon a flat table about one metre away from the candidate's eyes. Five large test skeins (pure green, pure red, rose, pure blue, and yellow) are separated from a collection of five small,

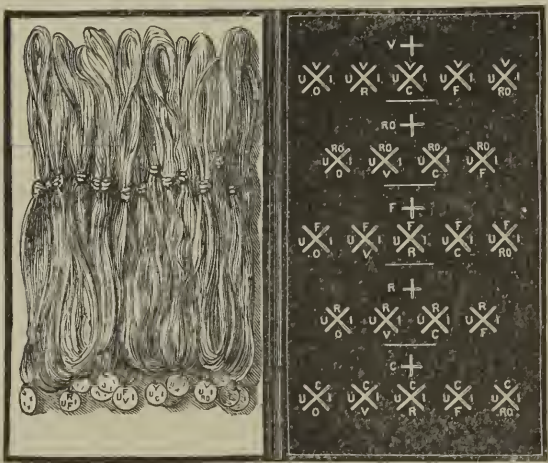


FIG. 16.—OLIVER'S WORSTED TEST.

pure match skeins, each being a pure tint of definite intensity of one of the colors of the large skeins, and eighteen small confusion skeins of the same intensity, each containing a mixture of certain definite percentages of two or more of the colors of the principal skeins. Each skein is colored with a vegetable dye, and each match and confusion skein is designated by a small black metallic bangle, upon which is marked the initial of

Dr. Oliver writes me that his worsted test is in use on some of the largest railway systems, and is being received more and more throughout the United States.

the color and its degree of color-saturation in such a manner as not to be understood by any one but the examiner. (See Fig. 16.) One eye of the examinate is to be tried at a time. One of the large test skeins (preferably the green) is handed to the candidate, and he is requested to select from the pile of wools the three nearest matches to this skein, and to lay them alongside of it in the order of their matching. The surgeon should go through the procedure, and then show the candidate exactly what is wanted, taking care, however, so to disarrange his choice that it will be impossible for the candidate to gain any knowledge from his selection. The letterings upon the tags of the chosen wools are then to be registered, in the order of choice, upon a properly arranged blank. This finished, the selected wools are to be replaced among the general mass, and the same method of selection continued with the rose, the red, the blue, and the yellow."[46]

THE AUTHOR'S WORSTED TEST.

From the fact that color-blindness varies widely in degree and that in matching colors one case does not make the precise mistakes of another, it follows that any test which uses an arbitrary selection of colors, or which is limited to a small number of match and confusion skeins, curtails the choice and makes the defect more difficult to discover.

In the author's test the assortment of worsteds is sufficient to allow the candidate full sway in matching the sample color. It is also so constructed that the result can be recorded, and by glancing at the blank one can at once see the color and tint of the skeins

chosen. The set is made up of the following colors: Pure green, yellow green, blue green, olive, gray, drab, brown, yellow, salmon, pink, rose, red, blue, and violet. There are six tints of each color, evenly graded from the lightest to the darkest. There are five test skeins, viz.: I. Light pure green. II. Rose. III. Red. IV.

RECORD OF A PERFECT COLOR-SENSE.

	TEST I, GREEN.	TEST II, ROSE.	TEST III, RED.	TEST IV, BLUE.	TEST V, YELLOW.
Pure green . . . . A	1 2 3 4 5 6				
Rose . . . . B		1 2 3 4 5 6			
Red C			1 2 3 4 5 6		
Blue . . . . D				1 2 3 4 5 6	
Yellow . . . . E					1 2 3 4 5 6
Yellow green . . . F					
Blue green . . . . G					
Gray . . . . H					
Drab I					
Pink . . . . J					
Brown . . . . K					
Salmon L					
Olive . . . . M					
Violet . . . . N					

Blue. V. Yellow. To enable the examination to be made by laymen, a bangle bearing a concealed letter and number is attached to each skein. The letter denotes the color, and the number (1 to 6) denotes the tint. For example: A 1 indicates the lightest tint of pure green; K 6, the darkest tint of brown.

In making an examination the light-green skein

(Test I) is laid aside and the candidate is asked to match it from the confused heap placed before him. This being done, the examiner takes the selected skeins and records the number of each in the first column under the head of Test I. (See table.) It will be noticed that each color has been given a letter, and in recording the tint of any skein selected it is sufficient to place the number in the space after its corresponding letter. Having made a record of Test I, the worsteds are mixed and we proceed with the rose skein (Test II), etc., always recording the result of one test before proceeding to the next.*

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* This test set is made by A. S. Aloe Co., St. Louis, and comes in a neat box with directions and sample blank.

CHAPTER VII.

PSEUDO-ISOCHROMATIC TESTS; CONTRAST TESTS; SPECIAL TESTS.

Pseudo-isochromatic Plates of Stilling.[47]—The remarkable facility with which the color-blind distinguish colors to which they are blind is due to an acute sensitiveness to differences in tint and intensity of light. The color-blind eye frequently perceives slight differences in tint better than the eye of normal color-perception. For instance, to a color-blind eye an intense red appears yellow. On admixing blue the color-blind eye will see a gray, while the normal eye sees a reddish blue; on continuing the admixture of blue the color-blind will see grayish blue, while to the normal eye the mixture still appears bluish red. But if, instead of blue, yellow is mixed with red, the color-blind eye will already perceive a very pronounced yellow when the normal eye still sees red or orange. This explains the success in matching colors often observed in the color-blind, as well as the difficulty of a speedy and certain diagnosis. In the pseudo-isochromatic plates Stilling seeks to deprive the color-blind of any aid in matching colors by selecting those which appear identical not only in tint, but also in intensity of light. Aided by a red-green-blind painter and a blue-yellow-blind teacher he was able to determine the interchangeable colors. On a colored surface of convenient size he painted a spot of the color mistaken for it; he then toned or modified this

spot until the color-blind eye could not distinguish between the spot and the surface. In this manner he built up two classes of interchangeable colors, as follow:—

First Class.

Fiery red,	interchangeable with	dark yellow.
Intense green,	" "	dull loam-color.
Faint rose,	" "	bright gray.
Faint blue-green,	" "	bright gray.

Second Class.

Fiery red,	interchangeable with	intense gold-yellow.
Greenish yellow,	" "	faint bright blue.
The last two,	" "	bright gray.
Green,	" "	blue.
These two,	" "	dark gray.

Stilling then constructed ten plates, each plate containing four squares, and arranged in such a manner that the squares of one color form letters and figures and those of the confusion color the groundwork.

The test-plate is held in a good light and the candidate required to distinguish the letters or figures. An important feature of this test is that there is no inquiry as to color, but only as to letters and figures. Stilling's plates are of practical value, and should be used in conjunction with the worsted test.

Mauthner's Pseudo-isochromatic Powders.—Mauthner's method is described as follows[48]: Thirty-four little bottles contain variously-colored powders; four of them each one powder in the fundamental colors. All the other bottles contain, in superimposed layers, either two shades of the same color or two totally different colors. The person examined is required to separate the bottles

into two divisions,—namely, on one side only the one color, even if of varying tints; on the other side the bottles with different colors.

Donders's Pseudo-isochromatic Patterns.—Worsted patterns, which are pseudo-isochromatic to the color-blind person, are wound around a piece of wood in striped patterns, and the patient is asked to count the stripes. The stripes have the thickness of two threads of worsted. With this method three kinds of patterns are obtained: one which is not, or only with difficulty, recognized by those red- or green- blind; a second one, the stripes of which are easily recognized by the red-blind, but with difficulty or not at all by the green-blind; and a third one, the stripes of which are easily seen by those green-blind, but with difficulty or not at all by the red-blind.[49]

Simultaneous Contrast Tests.

Colored Shadows.—If a white and a colored light are allowed to fall simultaneously upon a colorless surface and some object—a lead-pencil—be placed between this surface and the two lights, one of the two shadows which are cast upon the surface will appear of the same color as the colored light and the other of its complementary color. If a colored light only is used, the shadow cast will appear of the complementary color of the light. Thus, a red light will throw a green shadow, a blue light a yellow shadow. To the color-blind the shadow appears uncolored, black or gray. The experiments can be so perfected that by regulating the light the contrast shadows appear stronger or weaker according to the intensity of the lights. This test cannot be recom-

mended for examinations on a large scale, because the persons to be examined, even if they should perceive no colored shadow, may guess the color. Therefore, a large number of shadows would have to be cast,—red, green, etc.,—when a color-blind person, who sees them all colorless, would not always guess correctly.

Meyers's Tissue-paper Test.—Meyers's test consists of a square of red paper with a gray border, the whole covered with a piece of tissue-paper. To the normal eye the border appears green,—complementary to the color of the square. A color-blind person who does not recognize the color of the square will not be able to tell the complementary color of the border.

Pflüger's Tissue-paper Test.—Pflüger has modified Meyers's test by using letters of gray or black paper laid on colored grounds, with tissue-paper covering. The letters appear in the complementary color. Black print on a red ground appears light green; on a yellow ground, blue; on a green ground, purple; on a blue ground, yellowish brown; on a violet ground, yellowish green.

Contrast Experiment of Ragona Scina.—In bright daylight we take a strip of thick white paper which is folded in the middle at right angles, with a blot of ink on both inner halves, and some colored glasses. If the right angle is divided into halves by a red-glass plate and we look at the glass from above, the one spot appears red by reflection, the other bluish green by refraction. Color-blind persons do not perceive the contrast color, but call the green spot blackish or bluish black.

Special Tests.

The Spectroscope.—The spectroscope, while a valuable aid to the scientific study of color-blindness, is not a satisfactory test for every-day work. It is of service as an auxiliary test to be used by the expert. Fig. 17 shows Browning's pocket spectroscope, which consists of a compound direct-vision prism placed in a sliding tube, at one end of which there is a lens and at the opposite end a slit to admit the light. By the aid of this instrument the color-blind can tell us whether the spectrum appears shortened and what colors he sees. The ordinary red-green-blind person sees but two colors

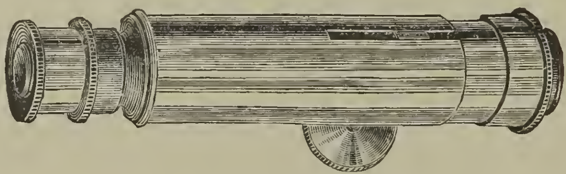

Fig. 17.—Browning's Spectroscope.

(yellow and blue), with a gray or neutral band between them. Violet is usually designated as blue, and there is a shortening of the left end of the spectrum when the intensity of the light is diminished. Berry[50] says: "Many investigators describe the spectrum of the color-blind as continuous, although only containing two colors, no portion appearing gray. This is due to the way in which they have conducted their examinations. If a very luminous spectrum be used, the images of the slit formed by the rays lying on each side of those giving rise to the exact neutral line so overlap each other as to cover the image formed by those colorless rays. A less luminous spectrum, by diminishing the color-sensations

produced on each side of the neutral line, which in all cases are described as feeble, permits of the impression of a gray line separating the two colors composing the spectrum, although the line may not be very sharp." Magnus makes his color-blind patients pick out those worsted samples which appear identical to the colors

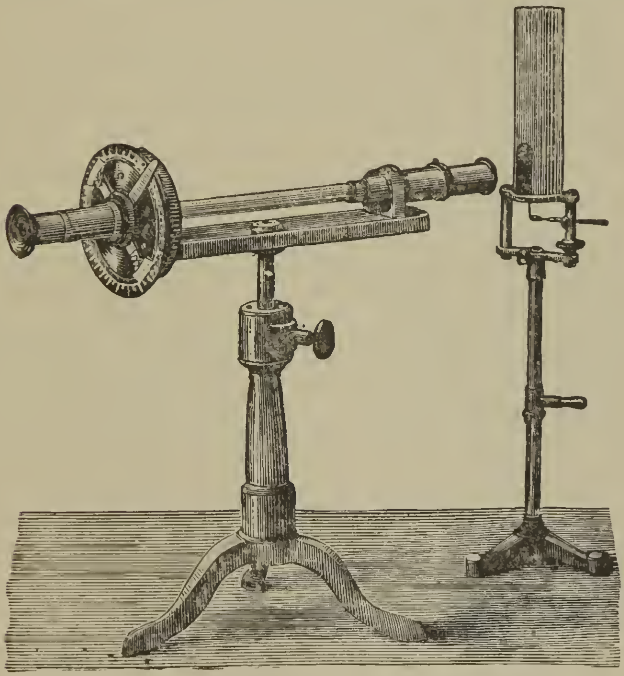

FIG. 18.—MITSCHERLICH'S POLARISCOPE.

seen in the spectrum, and thus reproduce the entire spectrum.

Polariscope.—The polariscope (see Fig. 18) consists essentially of two parts: a quartz plate for polarizing the light (polarizer) and a Nicol prism for exhibiting the fact of light having undergone polarization (analyzer).

If the quartz plate be very thin (between the twentieth and sixtieth of an inch) and of uniform thickness, the light transmitted through the Nicol prism will be of a uniform tint,—say, for instance, red. If the prism be slowly turned the disc of red light will change through all the tints of the spectrum. If a double-refracting prism be used as analyzer two color-discs are seen, each of which goes through the same changes of color and intensity as the single disc. The candidate is requested to turn the prism until the two discs become of the same tint, and the angle is noted. The color-blind individual is unable to match the discs, and declares two dissimilar tints to be the same.

Maxwell's Disc.—Two colors are represented on a rapidly-revolving disc, and are modified as to tint, saturation, and intensity until they appear alike to the candidate. Color-blindness is exposed if he declare two dissimilar colors to be the same. While this method is perfectly reliable and is very useful for the accurate study of a single case, it is not suitable for the examination of numerous persons, because the continued changes made in the colors consumes too much time and is very fatiguing to the examiner.

Quantitative Estimation of the Color-Sense.

Donders's Lantern.—This instrument consists of a blackened cylinder with a circular disc containing a red, green, blue, and white glass. In front of the light is placed a metallic slide with perforations ranging from 1 to 20 millimetres in diameter. Having tested and recorded the average size of the opening required by the normal eye to distinguish each color at 5 metres, the candidate is

placed at this distance and is asked to name the colors as the disc is rotated in front of the flame. If he recognize the red light through the 1-millimetre opening, his color-sense is normal, $= \frac{1}{1}$. If an opening of 20 millimetres is needed, his color-sense $= \frac{1}{20}$. If he fail to recognize the color through the largest opening he is told to approach the light slowly, and if he see it at 1 metre his color-sense $= \frac{1}{100}$, etc.

Oliver's Color-Sense Measure.—The instrument (see Fig. 19) consists of a blackened perforated disc, in which

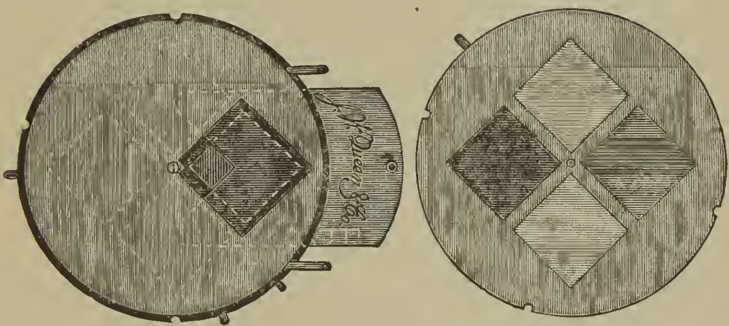

FIG. 19.—COLOR-SENSE MEASURE. (*Oliver.*)

there is inserted a movable, graduated slide. The disc is bolted to two circular cards, upon which are placed the three primary colors and blue and a series of confusion colors. The disc is placed at 5 metres distance, in a good light, and the candidate requested to name the color. By raising the graduated slide the amount of surface exposure is increased until the color is recognized. At this point we refer to the slide, read off the size of the opening, and record the color-sense as mentioned under the head of "Donders's Lantern." Oliver found that red requires $2\frac{2}{3}$ millimetres of surface ex-

posure to be properly recognized by the normal eye at 5 metres distance; yellow, a slightly increased area; blue, $8\frac{3}{4}$ millimetres; green, $10\frac{3}{4}$ millimetres; and violet, $22\frac{3}{4}$ millimetres. (See page 28.) It was also noticed that orange and violet were especially difficult to distinguish, and that the individual limit of color-perception varies considerably in healthy eyes.

Buxton's telechrome[51] is a combination of the worsted and lantern tests. "The contrivance is fitted with disc-carrying glass plates, which by gaslight show the following colors: pale grass-green, pale rose, bright red, bright blue, signal-green, and yellow. The instrument is placed in a darkened room fifteen feet from the patient, who remains in the daylight and matches the test skeins with the colors as they are displayed in the lantern, under varying degrees of light intensity."

Expedients to Satisfy Officials and Others.

Having found by one or more of the foregoing methods that the individual is color-blind, it may and often is necessary to satisfy the officials or friends of the man that he is unfit for any duty requiring the recognition of colored signals. In order to attain this object it is well to make the tests conform as much as possible to the signals in general use.

Flag Test.—For this test secure from the railroad company two or three dozen signal-flags—red, green, blue, and white—which have become soiled by much use. These having been placed on a table in a confused heap, the color-blind individual is asked to assort them, or he may be requested to pick out the danger-signals. A totally red- or green- blind person may mistake dirty

white for green, or confuse the reds, greens, and blues in picking out the danger-signals. As many color-blind persons do not exhibit their defect with this test, it becomes necessary to resort to a signal-lantern so modified as to imitate the appearances of signal-lamps at different distances and under the varying conditions of illumination caused by rain, fog, snow, and ice.

Lantern Test.—An ordinary switch-lantern with a four-inch opening should be so arranged that pieces of colored glass can be placed in front of the light. The colors to be used are standard red, yellow, pure light green, standard green, blue, and purple. The luminosity of the light can be varied by having at hand pieces of white (ground), ribbed, and different thicknesses of London-smoke glass. As red and green appear to the color-blind as one and the same color, only lighter or darker than the other, it is easy to deceive him by changing the luminosity of the light without altering its color. This can be done by diminishing the light or by placing pieces of ground or London-smoke glass before the colored light. By some such expedient we so alter the conditions under which he has been accustomed to see colored lights that he is liable to blunder and make mistakes, which must convince the most incredulous that he is not to be relied upon to distinguish colored signals.

CHAPTER VIII.

ACQUIRED COLOR-BLINDNESS.

INJURY or disease of the eye or brain may cause various disturbances of the chromatic sense, which, to some extent, show the same phenomena observed in congenital anomalies. Thus, we distinguish *total color-blindness*, *partial color-blindness*, and a *feeble chromatic sense.* The first characteristic which distinguishes the acquired from the congenital defect is that along with the loss of color-sense there is impairment of the visual acuity. With the dimness of vision is also associated a diminished perception of light. In some cases there is a constriction of the field for white and colors; in others, a central color-scotoma with a normal peripheral field. In the great majority of cases acquired defects of the chromatic sense are due to disturbances or destruction of the conducting nerve-fibres, and the character of the phenomena observed is more or less dependent upon the form and extent of the lesion (neuritis, atrophy, or tobacco-amblyopia).

COLOR-BLINDNESS FROM NEURITIS.

The vision in neuritis, even when the optic nerve is greatly swollen, may be but slightly impaired, while at other times, often with little apparent change in the nerve, we may find complete blindness. The field of vision for white is usually only slightly and concentrically narrowed, and soon turns to normal again, while the degree of color-disturbance may vary from total

color-blindness to but slight limitations of a single color. Jeffries reports an interesting case of monocular color-blindness from neuritis which occurred in the practice of Dr. Nuel. A railroad employé "had been in the hospital with retrobulbar trouble in the right eye, which recovered to two-thirds vision. One night, being required to set signals, he set the *green* instead of the *red* and went back to his box. Presently, having occasion to pass the signal again, he had doubts about the color, and, looking at it with the left eye in close proximity, he found he had made a mistake. He, fortunately, had time to change the signal and avoid an accident. He then ascertained that he could not distinguish with his right eye red or green from white light. He was frightened enough to consult a physician, who sent him to Dr. Nuel, who determined the above."[52]

Color-Blindness from Atrophy.

In atrophy of the optic nerve, whether primary or secondary to some other affection, the *central vision* and *light-sense* are diminished at an *early stage* of the disease. The visual field for white is never normal, but gradually contracts concentrically or by irregular indentations until it finally engulfs the fixation-point. The sense of color soon becomes diminished and then lost, first for red and green and last of all for blue.

Color-Blindness from Injury.

There are many cases on record in which a severe injury has been followed by a permanent or transient loss of the color-sense. Jeffries mentions Wilson's case of a physician who was thrown from his horse, experi-

encing a severe concussion without fracture of the skull, followed by long-continued cerebral excitement. He had been an excellent anatomist and fond of sketching in colors. On recovering sufficiently to notice distinctly objects around him, he found that his perception of colors, which was formerly normal and acute, had become both weakened and perverted, and it continued so. He had laid aside sketching in colors as a hopeless and unpleasant task. Flowers had lost more than half their beauty for him, and he recalled the shock he had experienced, on first entering his garden after his recovery, at finding that a favorite damask rose had become, in all its parts,—petals, leaves, and stem,—of one uniform, dull color, and that variegated flowers, such as carnations, had lost their characteristic tints. The rainbow was, to him, a white semicircle, like a lunar rainbow. Wilson, on testing him, found that he recognized blue and yellow, but could not distinguish red from green. In short, in consequence of the accident, he had passed into what is the condition of the congenital color-blind.[53] Fontan[54] describes the case of a soldier who suffered from transient color-blindness as the result of an injury received in an explosion. He was wounded on the forehead, above the right brow, and was unconscious for twenty-four hours. The next day the vision of his right eye was impaired, and every object had a blue tint. The visual field was contracted to a minimum. On the second day yellow was mistaken for red and very light yellow for blue. On the third day all colors appeared blue, and on the fifth day the right eye recognized all colors except the very light tints. Complete recovery followed.

Posada-Armiga[55] records the case of a colonel who was struck by a musket-ball in the left temple. For several days he was unconscious and delirious. When consciousness returned it was discovered that he had entirely lost his memory, so that he had to be taught the names of the commonest objects. He was totally color-blind, very deaf, and the senses of taste and smell were lost. His hearing, smell, and taste gradually returned, but it was two years before he could again distinguish colors ; he recognized red first and green last.

Field of Vision in Nerve-Lesions.

The examination of the visual field with colored objects is of great practical importance and is a more delicate test than that with white. We are thus enabled to detect certain nerve troubles in their early stages before the visual acuity has become affected, and at the same time we receive valuable information as to the progress of the disease. Although the physiological limits of the color-fields vary considerably in different persons (5 or 10 degrees), yet it is possible to designate a visual field as normal when certain characteristic conditions are present. Dr. Augstein[56] says: "Above all, the concentric arrangement and the normal succession of the color-limits appear of the greatest importance. Then it is to be noted that the color-blind zone which lies between the limit for white and that for blue has a breadth of about 10 degrees; close by the limit for blue lies the limit for yellow, both often merging into each other; then follows the limit for red; lastly, that for green, which has the smallest field. (See Fig. 20.) The limits for red and green in the physiological state vary more

than those for blue and yellow, and it is generally known that under pathological conditions they are first and most altered; next to this the limits for yellow, in many pathological conditions, are first changed. Yellow lying

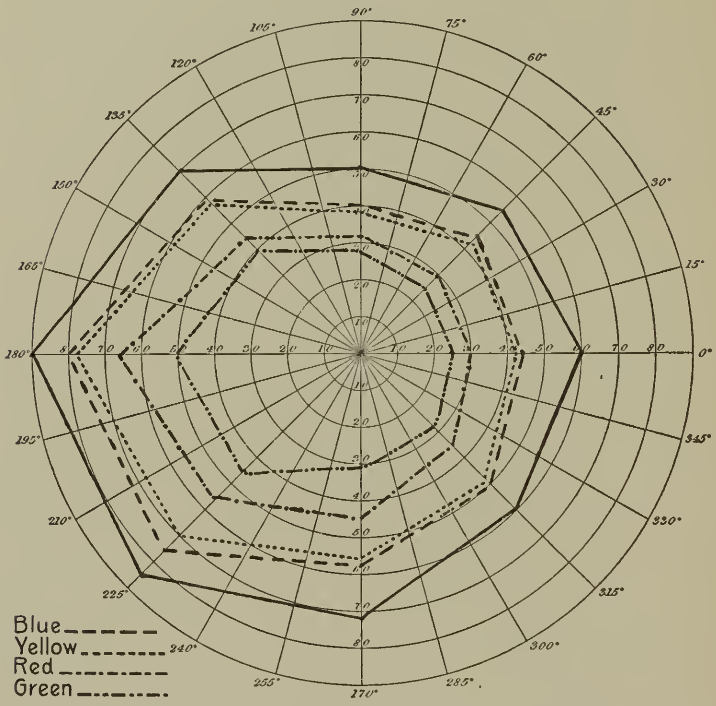

FIG. 20.—DIAGRAM OF THE NORMAL FIELD OF VISION FOR WHITE, BLUE, YELLOW, RED, AND GREEN.

The outer, continuous line indicates the limit of the field for white, and the broken lines indicate the limits of the color-fields.

near the blue in the healthy state, it will at once awaken suspicion to see it move toward and even beyond the limits of red and green. We must be more on our guard if we have to deal with a contraction of the limits for red and green; but from my experience I consider

it to be pathological when in the upper, inner, and lower parts of the field the red limit sinks below 25°, the green limit below 20°; and in the outer part, the red limit below 40°, the green limit below 30°. *Re-entrant angles, even for one color, with normal outer limit, intermingling of the color-limits, destroying their normal succession and changing concentric curves into zigzag lines must always be considered as pathological.*"

Separate Centres for Light-Sense and Color-Sense.

There are many intra-ocular affections and central disturbances of vision depending upon abnormal circulation in the brain, in which the sense of color is preserved, however reduced the sensibility for light. We also meet with cases of amblyopia with central scotoma in which the visual acuteness improves and the sense of color remains defective or *vice versâ.* This seems to demonstrate the existence in the brain of separate centres for light-sense and color-sense. Steffan[57] reports a case of acquired color-blindness of both eyes, in which there was retention of normal light-perception and acuity of vision. Samelsohn[58] and Bjernum[59] report cases of typical left-sided hemianopsia. In Bjernum's case there was total color-blindness in the left half of the field. The margin passed precisely through the fixation-point in a vertical direction. There was an acute brain trouble; at least, the patient complained of a severe headache and died suddenly.

Tobacco-Amblyopia—Chronic Retrobulbar Neuritis.

The excessive use of tobacco, whether by smoking or chewing, etc., may set up a low grade of inflammation

of the optic nerve (tobacco-amblyopia). It is most frequently found in middle-aged men who chew or smoke cheap, moist tobaccoes and use alcohol. The susceptibility to the nicotine poison varies with individuals; some persons have been known to smoke from twenty to thirty cigars a day for years with impunity, while others show the characteristic symptoms after very moderate smoking. The first symptom noticed is a dimness of vision, which may come on so gradually that the patient is unable to tell exactly when it began. Both eyes are usually affected to the same degree, which distinguishes tobacco-amblyopia from atrophy of the optic nerve, neuritis, cataract, etc., in which the dimness of vision is almost always more pronounced in one eye than in the other. Another characteristic symptom, first described by Arlt, is nyctalopia,—*i.e.*, vision is better in the evening than it is in the day-time. This is more apparent than real in tobacco-amblyopia, for, although at dusk the pupil is larger and admits more light to the healthy portion of the retina, the central vision, on account of the scotoma, remains the same. By scotoma is meant an isolated spot in the visual field which is not susceptible to external impressions; it may be *absolute*, blind to light of any kind; or *relative*, blind to colors. The ophthalmoscopical examination in tobacco-amblyopia is negative, or, perhaps, we may observe a dusky-red appearance of the disc in the early stages of the disease, and a slight paleness at the temporal side of the disc in more advanced cases. An examination by means of the perimeter shows no change in the limits of the visual field for white or colors, but if a small square of pale-green or red paper (one, two, or three millimeters) be

carried along the arc it will usually be found to undergo a change in the region of the fixation-point; green appears gray and red appears dark brown. The shape of this color-scotoma is usually an horizontal oval which includes the fixation-point and extends from the macula to the blind spot. In more marked cases, where the visual acuity is much diminished, the color-square is not seen at all in this central area. Finally, in extreme cases, even light-perception is lost and the scotoma becomes absolute. As the outer limits of the visual field

FIG. 21.—CENTRAL SCOTOMA TEST.

always remain intact, patients are able to find their way about, although debarred from all work which requires direct fixation.

A convenient method of testing for a color-scotoma without the aid of a perimeter is to request the patient to cover one eye and stand with his back toward the light. He is then to fix his uncovered eye upon the nose of the surgeon, who takes up a position about fifteen inches in front of him. The small square of colored paper (see Fig. 21) is then quickly brought in the patient's line of vision and he is asked to name the

color. If he fail, the square is slowly moved in different directions until the color is correctly named. It is well to have several squares of different colors at hand, in order to determine the accuracy of the patient's statements. In this manner it is possible to estimate pretty closely the size of the color-scotoma.

Prognosis.—Tobacco-amblyopia is a chronic disease requiring a series of months to reduce the vision to the minimum. Complete restoration of sight usually takes place, even in bad cases, if the disease is not of long standing and if the patient honestly obey instructions.

The *treatment* is total abstinence from tobacco in any shape or form. The patients readily promise to give up the use of tobacco, but many find the temptation too strong and secretly indulge in one or more "pipes" daily. In these cases little progress is made and the disease drags along slowly for many months. If tobacco is given up, recovery usually takes place in from two to six months. To accelerate the cure we may employ iodide of potassium in large doses or strychnine hypodermatically ($\frac{1}{30}$ grain daily). It is apparent that railroad employés with acquired defects of the chromatic sense are more liable to cause accidents than the congenitally color-blind, because along with the color-blindness is a marked diminution of visual acuity. Hence the necessity of requiring all employés to submit to examinations at frequent intervals.

St. Clair Buxton[30] cites a case of tobacco-amblyopia in which the patient was able to name and match colors, but would have confused red and green at a distance of one hundred feet because of the existence of a relative scotoma.

Thomson says[30]: "A disease once excited in an organ by any toxic agent, even if cured, will be very apt to return if the poison be again administered. Tobacco- and intoxication- amauroses are good examples of this law. Therefore, if an individual once suffer, he is extremely liable to have a relapse on the slightest provocation; and inasmuch as we know by experience that the drinking and smoking habits are very rarely permanently overcome, we cannot be in error or work a hardship when we advise that all employés of railroads or at sea, who drink or use tobacco in excess, be critically and from time to time examined, especially for the sense of color; and if it is found that there is any reason to believe that the scotoma for red or green exists, or has existed, it is best to give our corporations the benefit of any doubt by striking all such suspects from the rolls."

The Disposition of the Color-Blind.

Having ascertained that the chromatic sense of an individual is defective, the surgeon must decide whether the defect is of such a nature as to warrant his discharge or whether he can with safety be allowed to retain his position. If the person in question is an applicant for employment, even a slight defect of the color-sense should be sufficient ground for rejection. If, however, we have to deal with an old employé, one who, perhaps, has discharged his duties in a satisfactory manner, justice demands that his interests be studied so far as is consistent with safety. Holmgren says: "We here encounter great difficulties, and it will be seen that it is not possible to settle the question summarily,—that is, that a well-defined limit cannot be traced. In such cases the phy-

sician should always, when he discovers a defect in the chromatic sense, give a certificate which should indicate its nature. These indications include the diagnosis: *complete red-blindness*, *complete green-blindness*, *incomplete color-blindness*, or *a feeble chromatic sense.* We are convinced that every case of complete color-blindness of both kinds, as well as every case of incomplete, of the higher degrees, should be immediately discharged. But, as regards those who may be retained, it is clear that the first question concerns those who, at the time of the trial, were regarded in the diagnosis only as having a feeble chromatic sense, and then those who in the first test merely confounded gray with the sample color. But we do not venture to lay this down as a principle, for, if it should be proved that these individuals can generally distinguish the light of colored lanterns with sufficient accuracy, this does not prove that it is so in every case, and especially not at every distance required in the service." No employé should be dismissed until he has had the benefit of an examination at the hands of an expert, who should satisfy himself as to the nature and degree of the defect by the various methods at his command.

CHAPTER IX.

Pennsylvania Railroad Company's Instructions for Examination of Employés as to Vision, Color-Blindness, and Hearing (1880).[60]

The examination will be made as to vision, color-sense, and hearing, and the following apparatus will be used: 1. A card or disc of large letters for testing distant sight. 2. A book or card of print for testing sight at a short distance. 3. An adjustable frame for supporting the print to be read, with a graduated rod attached for measuring the distance from the eye while reading. 4. A spectacle-frame for obstructing the vision of either eye while testing the other. 5. An assortment of colored yarns for testing the sense of color. 6. A watch with a loud tick for testing the hearing. 7. A book or set of blanks for recording the observations. 8. A copy of an approved work on "color-blindness."

Acuteness of Vision.—For distant vision place the test disc or card in a good light, twenty feet distant, and ascertain for each eye separately the smallest letters that can be read distinctly, and record the same by the number of that series on the card.

Range of Vision.—For near vision ascertain the least number of inches at which type D = 0.5, or $1\frac{1}{2}$, can be read with each eye, and record the result.

Field of Vision.—Let the examiner stand in front of the examined, at a distance of three feet, and direct the examined to fix his eyes on the right eye of the examiner, and keep them so fixed; let the examiner

extend his arm laterally and, opening and shutting his hands, let him by questions satisfy himself that his hands are seen by the examined without changing the direction of the eyes, recording the result as good or defective, as the case may be.

Color-Sense.—Three test skeins—*A*, light green; *B*, rose; *C*, red—will be used, with the colored yarns attached to the stick; of the latter there are forty tints, numbered from 1 to 40, and arranged in three sets—*a*, *b*, *c*—of which the odd numbers correspond to the colors of the test skeins, while the even numbers are different, or "confusion colors." The first set is to test for color-blindness, the second to determine whether it be red- or green- blindness, and the third to confirm the opinion formed from the first or second test.

Place the test skein *A* at a distance of not less than three feet, and, without naming the color, direct the person examined to name the color and to select from the first twenty tints, or set *a* of the yarns on the stick, ten tints of the same color as skein *A*, stating that they do not match, but are different shades of the same color. Record the numbers of the tints so selected. Do the same with skeins *B* and *C*, using for *B* the tints from 21 to 30, and for *C*, the tints from 31 to 40. If the odd numbers are selected readily, the examination may be gone over very quickly. When color-blindness is detected any one of the even numbers, or "confusion colors," may be used as a test skein, and the man may be directed to select similar tints, when he will most probably choose odd numbers, which should be recorded, stating the number on the stick of the "confusion color" used for a test, and then giving the numbers chosen to

match it. Then a soiled white flag should be shown and the man be directed to select tints to match it, which should be recorded; next a green, and finally a red flag.

All of the particulars are to be recorded as the examination proceeds, not leaving it to memory. Use the numbers in recording; the letters indicating the set need not be used. Note whether the selection is prompt or hesitating by a distinct mark after the proper word on the blank form. When deficient color-sense is discovered and variations in the mode of testing are made by the examiner or examined, they should be noted under "Remarks," or on a separate sheet to be referred to if the blank is not large enough.

Hearing.—Note the number of feet or inches distant from each ear at which a watch, having a tick loud enough to be heard at five feet, is heard distinctly, using a watch without a tick, or a stop-watch, to detect any supposed deception, and the number of feet at which ordinary conversation is heard.

Explanations.—The test card contains letters numbered from 20 (XX), or $D = 6$, to 200 (CC), or $D = 60$. Those measuring three-eighths inch and numbered 20 (XX), or $D = 6$, are such as a good eye of ordinary power sees distinctly twenty feet, or six metres, distant. If a man see distinctly only those marked C (or 100), his acuteness of vision, V, is equal to $\frac{20}{100}$, or $\frac{1}{5}$. If he see XX (or 20), then V is equal to $\frac{20}{20}$, or 1, and his sight is up to the full standard. This mode of statement indicates the relative value of the sight examined, and should be used in the records. If one eye is $\frac{20}{20}$, or 1, and the other not less than $\frac{20}{50}$, or $\frac{1}{2}$, with or without glasses, the sight may be considered satisfactory.

The power of discerning small objects at the reading-distance is tested by the small print, and good sight may be assumed if one eye can see at twenty inches the matter marked $1\frac{1}{2}$, or $D=0.5$, while the other distinguishes not less than $4\frac{1}{2}$, or $D=1.5$. The small print should then be brought to the point of nearest vision for each eye, and that point mentioned in inches. A good eye should be able to read No. $1\frac{1}{2}$ at twenty inches and have a range of vision up to ten inches.

The color-test will indicate whether the man is deficient in color-sense. The colors are arranged in three sets,—one of 20 and two of 10 each. The odd numbers are the colors similar to the test skeins, and the even numbers are the "confusion colors," or those which the color-blind will be likely to select to match the sample skeins or colors shown him. The first 20 (*a*), numbered from 1 to 20, have green tints for the odd numbers, or test colors. In the second (*b*), 21 to 30, the test colors are rose, or purple,—a combination of red and blue; and in the third (*c*), 31 to 40, they are red. Ordinarily, the test will be with each set separately, but the whole 40 may be employed on any test skein. Anything but green matched with green indicates a defect in the color-sense, for which use set *a*. The test with the second set indicates whether red- or green- blindness exists. The odd numbers from 21 to 30 are purple. If either of these is matched with test skein *B* nothing is indicated, as they must appear alike to a color-blind person; but if blue is chosen red-blindness is indicated, and if green, then green-blindness is established. The third set (*c*) is scarcely needed, but may be used in confirmation of or in connection with the last as to red or

green defect. When the numbers of the tints selected are recorded in the proper blank, color-blindness will be indicated in those instances where even numbers appear, and suspicions will arise where numbers beyond 20 are used with test skein *A*, and under 21 or beyond 30 with *B*, and below 31 with *C*.

Further tests should be made of those found to be color-blind with the usual signal-flags, requesting them to name each color, shown singly, and to match the colors of them from the tints on the stick and with colored lamps; and, finally, to state what they understand them to mean as signals. It will be well not to dwell on the examination of a man found to be defective in color-sense or in vision, but to pass over each examination with the same general care, and afterward send for those giving indications of defects to come in singly for further examination. The examination should be private as far as practicable, especially excluding persons who are to be subsequently examined. Inability to name colors accurately or to distinguish nicely as to differences in tint is not to be taken as an evidence of color-blindness.

In testing as to hearing, if the watch used can be heard at five-feet distance, and the person examined hears it only at one foot, his hearing would be 1–5, and may be recorded in fractions. Conversation in an ordinary tone should be heard at ten feet.

It should be understood that all employés examined, failing to come up to the requirements of the above standard, shall be accorded the benefit of a professional examination. When acuteness of vision is below the standard adopted, it may be possible to restore full

vision by proper glasses when it is due to optical defects, known as near-sight, far-sight, or astigmatism, or by other medical or surgical treatment, and useful men may then be retained in the company's service. [These rules and regulations, having been approved by the Board of Managers, have been put into effect on the Pennsylvania Railroad, under the general supervision of Dr. William Thomson, of Philadelphia, and give entire satisfaction.]

In order to show how the Pennsylvania Railroad Company keeps its records of these examinations, we submit the following fac-simile of an actual blank[61] :—

WEST JERSEY RAILROAD COMPANY.

CAMDEN, January 19, 1883.

Examination of sight and hearing of James A. Morris, aged twenty-two, employed as locomotive fireman, applicant for

ACUTENESS OF VISION.		RANGE OF VISION.		
The number of the series seen at twenty feet distant.		Least number of inches at which type D—0.5 in test-type pamphlet can be read.	Right eye, 4½ inches.	Left eye, 4½ inches.
Right eye	20–30	FIELD OF VISION.		
Left eye	20–20	Good or defective . . .	Good.	

Color-sense.

Test-skein submitted.	Name given.	Numbers selected to match.
A—Green	Green	3, 26, 24, 7, 11, 22, 15, 5, 1, 17, 28, 9, 19, 30, 13.
B—Rose	Red	37, 33, 29, 12, 39, 31, 21, 35, 25, 27, 23.
C—Red	Red	37, 33, 31, 35, 23.

Second Color-test.			Third Color-test.		
Number shown.	Name given.	Numbers selected.	Flag shown.	Name and use given.	Numbers selected.
24	Green.	26, 22.	Soiled White.	Safety, White.	2, 4, 6.
39	Yellow Red.	Could find no match.	Soiled Green.	Caution, Green.	36, 38.
30	Blue.	26.	Soiled Red.	Danger, Red.	37, 33, 31.

Selection prompt or hesitating :
Prompt.

Hearing.

Right Ear.		Left Ear.	
Watch.	Conversation.	Watch.	Conversation.
8 feet.	20 feet.	8 feet.	20 feet.

Remarks :

Escaping steam prevented watch test.

J. J. BURLEIGH, *Examiner.*

Acuteness, right eye defective. Range, good. Field, good. Color-sense, defective. Hearing, see Remarks.

JOS. CRAWFORD, *Superintendent.*

NOTE.—Those approved, marked "Appd."
Those not approved, marked "Not Appd."

CHAPTER X.

Description of Oliver's Series of Tests for the Detection and Determination of Subnormal Color-Perception (Color-Blindness), Designed for Use in Railway Service.

As it is a well-known fact, both from theoretical and practical stand-points, that many "Color-Blinds," especially those of medium grades, have the power of differentiation, even by daylight, of the most difficult colors, when placed at the ordinary one-metre distance of wool selection employed in the detection and determination of "color-blindness," Oliver has been induced, through a hope to overcome the dangers that might arise from this power in situations, such as railway, marine, and naval service, where the safety of lives and the protection of property is ofttimes almost solely dependent upon proper recognition of color at great distances and frequently through the intervention of more or less translucent media, to combine two modifications of his method of color-selection with a simplified plan of his former procedure by which all candidates are placed in the actual position of after-work and under exactly similar circumstances as during their daily employment.

To effect this purpose in railway service, he divides his method into three parts:—

1. The selection and registry of a definite number of loose wools from twenty-three pure and confusion match skeins, thrown upon a dead-black surface one metre distant.

2. The selection and registry of the same number of similar reflected colors under various intensities of diffuse daylight stimulus, placed at distances that are requisite for safety.

3. The selection and registry of transmitted color under various intensities of artificial light-stimulus, placed at distances that are requisite for safety.

APPARATUS.

The material for the first part of the test is quite simple. It consists of all the wools comprised in the first shades, together with the five test skeins, of the series of wools described by him in 1886, associated with a piece of dead-black muslin, an explanatory sheet with the colors arranged in their proper order, and a spectacle-frame with a movable stop.

The second portion of the test consists of a tier of twenty-three shallow, open wooden boxes painted dead-black. These are placed upon an horizontal beam, which is supported by vertical posts or rods that are fifteen feet high. Each box has its inside surface so arranged as to face an observer placed in a line with the centre of the row at, say, one thousand feet distant. Every five boxes in the tier are separated by spaces equal to three times their own width, and every fifth box by a space that is double this width. Arranged above the middle of these boxes, and at a height that is equal to six times the height of the lower boxes, there is a large revolving box so made as to contain five partitions. The back face of each box has a greater space than the largest area of color to be exposed at any desired distance. The inner face of each side of the box contains a slot, into

which a wooden frame containing definitely-sized areas of colored bunting, equal to that which can be distinguished at the distance chosen by an average normal eye, is placed. Each color-frame has stamped upon it the designation of the contained color in the same nomenclature as he has employed upon the bangles that are attached to his series of wools. The partitions of the upper box contain the proper-sized surfaces of the five principal test colors that can be recognized by the average normal eye at the employed distance. In addition, there are a series of London-smoke tint and translucent glass discs intended for use in the spectacle-frame.

The additional material for the third part of the test consists of twenty-three definitely-sized chosen areas of transparent colored glass, each having a surface composed of concentric prisms of not sufficient power to produce commingling of diffusion circles with fellow-lights. These plates of glass are placed in the same character of wooden frames as those which are employed for the reflected colors, and each area of color has its proper color designation stamped upon its frame.

A series of registry blanks accompanies each set.

PROCEDURE.

The first part of the test is conducted by a modification of the ordinary Holmgren method (see page 70), and the result for each eye, as shown by reference to the attached bangle, is to be noted upon the first division of the registry blank, described farther on. If the examination show that the candidate has failed, then the entire test can be suspended, as the unfitness for work is plainly manifest; but in order to make the test complete,

in such a case, and thus serve as a check against any future legal disquisition, it is best to continue just as if the candidate had passed successfully.

For the second test the fixed apparatus can be placed anywhere upon the railway grounds. The wooden frames containing the match colors of bunting are placed in the lower tier of boxes, in any order whatsoever, just as if an examination with the wools thrown upon a table was being conducted. The five test colors of bunting in the wooden frames are slid into the slots in the partitions of the large upper box, and the "V" (pure green) area is wheeled into position. The candidate, employing one eye at a time, is now asked to designate by writing, upon a piece of paper, the number of the color area in the lower row (going from his left to his rght) that to him is the nearest match to the upper color. This experiment is to be repeated by each test color, preferably, but not necessarily pursuing the order of choice spoken of in the first test, until all the test colors have been used. The results thus obtained upon the slips of paper are then to be handed to the examiner, who, after having obtained the names of the numbers chosen for the occasion by the attendant, places the names in the second row of the regular registry blank shown on the next page.

To obtain different percentages of light-stimulus and to simulate as near as possible changes of character of weather (fog, rain, etc.), variously-tinted glasses can be placed in the spectacle-frame. If desired, however, it would be quite easy, and really proper, to test the candidate during these actual states of weather. As these changes, however, are so uncertain as to frequency and duration of happening, it will be best to limit this variety of experiment to those cases that are under suspicion.

BLANK FOR THE REGISTRY OF THE COLOR-SENSE.

__________ *Railway Company.*

__________ *Division,* __________ *Station.*

No. __________ *Date,* __________

Name, __________ *Age,* __________ *Address,* __________

Social condition, __________ *Present occupation,* __________

Applicant for __________

RIGHT EYE.			TEST COLOR.	LEFT EYE.		
Light chosen in Third Test.	Color chosen in Second Test.	Wool chosen in First Test.	Color Submitted.	Wool chosen in First Test.	Color chosen in Second Test.	Light chosen in Third Test.
			V			
			Ro			
			R			
			F			
			C			

Remarks, __________

____

____

__________, *Examiner.*

Result, __________

__________, *Superintendent.*

Report of Expert, __________

____

____

____

The third test is conducted in the same manner as the second, except that here the procedure is made during darkness and by the substitution of the plates of transmitted color, and the lanterns for the areas of bunting.

An experimental track with five open switches, about a thousand feet away from the apparatus, so arranged that the sidings would pass directly beneath the colors, would be useful after the regular examination had been completed, thus practically testing color-vision from locomotives running at full speed, and deciding the ability to differentiate the ordinary white, red, green, and blue signals at safe distances by the choice of track taken.

ADVANTAGES OF THE TEST.

In addition to the advantages shown, to refer to the first test alone,* the method may be said to have the following additional uses:—

1. *Much faster in time than any other proper method.* In the first test there are but five selections amongst twenty-three wools, which will at once decide, without continuance, whether the candidate possesses subnormal

* The headings of these advantages, which have been described at length by Oliver in the 1886 Transactions of the American Ophthalmological Society, are as follow:—

1. Five principal tests.
2. The wools are loose and separate.
3. The colors are all of equal relative intensity.
4. Each test skein has its value expressed.
5. The test can be employed by any educated layman.
6. Accurate notings of passing color-changes can be preserved and permanently kept for future comparison.
7. Written and verbal expression of the character and amount of subnormal color-perception can be given.
8. All the wools are of the same grade of manufacture.
9. All the colors are from vegetable dyes.
10. The use of a black surface or ground for testing.
11. Any order of testing may be pursued.
12. Quantitative determination as well as qualitative determination obtained at one sitting.

color-perception for near colors, thus accomplishing, in a few moments, as much as the Holmgren method.* In order to greatly expedite the second and third tests and, in consequence, to render the entire plan faster than any other, a dozen or more candidates may be examined at the same time, by merely handing them all slips of paper upon which they are all at once to register their names and the number of color or light in the lower row matching the upper test color exposed; care alone being taken by proper guards that there is no intercommunication.

2. *Selection of loose colors at a distance.* There is no other plan that in any way gives choice by loose and changeable selection of color at a distance. This has been done by naming the colors, so that, no matter how they are placed in the tier at the time of examination, they always hold their identity and can be properly registered upon the blank.

3. *No necessity for an expert except in doubtful cases.* Every "color-blind" candidate, as it were, becomes his own accuser and writes his individual verdict. The examiner at the station sends the properly-filled blanks, with his remarks, to the superintendent of the division, who marks the case "approved" or "not approved," obtaining, if necessary, in doubtful cases, the expert report before signing, whether "passed" or not.

4. *Employment of the same character of signal for testing as is used in daily routine.* This is a great advantage, and also avoids any source of error that might be said to arise through the question of the supplemental use of touch or the presence of characteristic dye-odor.

* The equal intensity of the colors employed destroys any objection to the possibility of escape by reason of fewness of match skeins.

5. *Placing the eye during testing at a distance necessary for future safety.* This is one of the great claims for the adoption of the method, because by it all dangers that might arise from the escape and employment of a class of subjects possessing what Wilson has so aptly termed "chromic myopia" are avoided.

6. *Bringing the eye during testing directly before the true condition of weather experienced while the organ is upon duty.* The color-sense is studied in the same place and under the same circumstances as is given to it while it is in actual service: this is most decidedly a great gain. Moreover, as has been shown, the plan can be made to give the best results in those cases and in those situations where detection is most needed, such as engineers and assistants placed upon running trains that are rapidly approaching fixed distant signals.

7. *Test and match colors all graduated in proportionate size.* This is important, as it is a well-known fact that two similar areas of different colors, placed at a definite distance or when surrounded by darkness, give misconceptions as to positions through difference in relative intensities, and thus tend to disastrous result. By carefully grading the test colors, as is here done, this complication is avoided, leaving the question of color, and color alone, to the competing candidate.

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